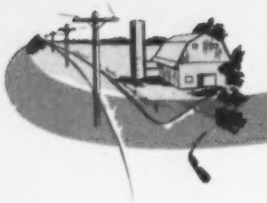
WESTINGHOUSE

Engineer

MAY 1953



FARMING—
A Story of Industrial Progress

The man with the hoe is well on his way to extinction. Until a few decades ago, the basic implements of farming were virtually the same as those used centuries ago—and so were the farmer's methods. Farming was, in short, a back-breaking, never-ending job. Not that it is a bed of roses now, but advances in the science of farming have been among the most significant of any industry.

A century ago two thirds of our working population were farmers; world-wide, this is still the average. But today, in this country, only one man out of seven is engaged in farming. Obviously this means that productivity has gone up, and significantly. A typical example is in wheat production. In 1900 it took 108 man-hours to produce 100 bushels; now it takes about 40 man-hours. Overall, each man-hour of farm work now produces 50 percent more than it did in the 1917 to 1921 period.

The means of accomplishing these tremendous gains are many and varied. Certainly there is no one reason that stands head and shoulders above all others. Better fertilizers, pesticides, and seeds, more scientific use of the soil, new crops, selective breeding methods, and many other factors enter the picture. But certainly the part that increased electrification of the farm has played cannot be overlooked.

Within the lifetime of many readers electricity was a rarity in farm homes. At the end of 1952 about 94 percent of the better than five million occupied farms in the country were electrified; individual states exceeded 98 percent. In the past ten years the farm use of electricity has increased 278 percent.

So far, however, only about 20 percent of the electrical energy used on the farm is applied outside the farmhouse. This indicates that while the farmer's home life—and particularly that of the farmer's wife—is far more convenient, electricity still has a big job to do in lightening his work burden. There is perhaps no area more suitable than that of the time-consuming routine "chores" that are a daily part of the farmer's existence. Much has already been done to mechanize and electrify these chores, but the full influence of technology has yet to be felt.

There are some striking examples of ways in which electricity has already been put to good use. The advantages gained are in many cases remarkable. Furthermore, the increase in the use of these methods is expected to be sizable. A few examples are illustrative.

Among the most familiar electrical devices is the milking machine. This device saves an estimated 50 to 65 percent in the time and labor usually required to milk a herd of cows. The power consumption amounts to between 1½ and 2½ kwhrs per month for each cow, or about 510 million kwhrs per year. But at present only about half the dairy farmers use electric milkers.

Another operation coming into widespread use is hay curing in the mow. In a typical case, a five-hp motor-driven fan forces air through a duct, and thence through the hay in the mow. This requires about 45 to 65 kwhrs per ton of hay. Present power consumption for hay curing is about 15 million kwhrs; estimated demand is 38 million by 1956.

A major problem on dairy farms is preventing the rapid growth of bacteria in milk. Refrigeration does the trick neatly. Typical immersion-type coolers range from 2- to 16-can capacity and use motors ranging from one half to two hp. This application alone now accounts for 488 million kwhrs per year; estimates place this figure at over 700 million by 1956. A newer development is bulk-tank storage in stainless steel tanks, into which milk is pumped directly.

Feed grinding is another operation that is being taken over by electricity. A one-hp motor can grind feed for 50 cows per day; and this operation can quite readily be made semiautomatic. The usual range of motors is from ½ to 7½ hp, depending upon the quantity of feed required.

Electric lights, too, perform several useful functions besides providing light to see by. Incandescent lamps are used to advantage in poultry houses to stimulate egg production; and infrared heat lamps are used as a source of heat for brooding pigs and chickens.

With the increased availability of electric power, farmers are also finding electric welders can be put to profitable use, accomplishing a saving in time as well as money in repairing broken equipment, or in manufacturing new devices.

These are but a few of the hundreds of ways in which electricity is now being applied on the farm. Irrigation is another major use, as is pumping the home water supply. Conveyor systems, elevators, hay hoists, and silo unloaders are growing applications. But the surface has hardly been scratched. Relatively, farming is still in its infancy as far as labor saving and increased productivity through electrification is concerned.

Technology was slow in getting around to the farmer's plight, although it has made sizable contributions in the past few decades. But much remains to be done. If the farmer is to keep pace with the population growth, he needs all the technical assistance he can get. Consider these figures. On the basis of present per capita consumption, the farmer in 1970 will have to produce about 3 *billion* more pounds of meat a year, 7½ *billion* more eggs, almost 8 *billion* more quarts of milk, and over 5 *billion* more pounds of fresh vegetables. A sizable task! And it puts the need for electrification in the class of a necessity, rather than a mere convenience.

More than ever, farming should be considered as an industry, and a huge one. Many of the solutions already applied in other industries can undoubtedly be adapted to fit its needs. It is not difficult to conceive miraculous changes in the farm in the next few decades. One far-sighted executive recently painted a possible picture of the farmer of the future sitting in front of an instrument board "merely pushing buttons: grinding feed for cattle, chickens, and pigs; then 'delivering' the feed to them; milking the cows, and cleaning the barn; filling the silo or feeding silage; drying and feeding hay; collecting eggs; cooling milk. . . . He is also in communication with the farm operator, who from a tower and by remote controls, is plowing the back forty, planting winter wheat in another area, and spreading manure in still another, observing the operation of all unmanned machines—by sight when possible, and by radar or TV when not in sight."

Sounds fantastic. But consider how equally fantastic some of our present automatic industrial processes would have seemed a few decades back. If adequate engineering effort is applied, this picture may well become reality. R.W.D.

WESTINGHOUSE Engineer

VOLUME THIRTEEN MAY, 1953 NUMBER THREE

On the Side

The Cover—One of the many steps in the preparation of lamp filaments is the drawing of the tungsten wire itself. It is this process that artist Dick Marsh used—plus a background array of typical filaments—to portray the theme of tungsten filaments on this month's cover.

• • •

Atomic power as a commercial business comes ever closer to reality. One indication is the recent announcement by Westinghouse of plans to build a multimillion-dollar plant for the express purpose of producing equipment developed for atomic power plants. Initially, production will be for government atomic projects; however, the establishment of this facility is based on the belief that private enterprise will play an increasing role in future non-military applications. The new plant, to be located near Pittsburgh, will house engineering, manufacturing, and sales of the recently formed Atomic Equipment Department.

• • •

One of the largest intra-company teletype relay stations in the country went into operation recently at Westinghouse. The new system presently has a total of 98 sending and receiving stations, which will reach an expected 150 by mid-1953.

The new relay system, located in the Company's Gateway Center headquarters in Pittsburgh, will be capable of receiving 33 messages at one time. Some idea of the volume to be handled by the new system is suggested by figures for the replaced equipment. In December of last year the old station sent a total of 133 000 messages, totaling almost six million words. The new station should roll up even more impressive figures.

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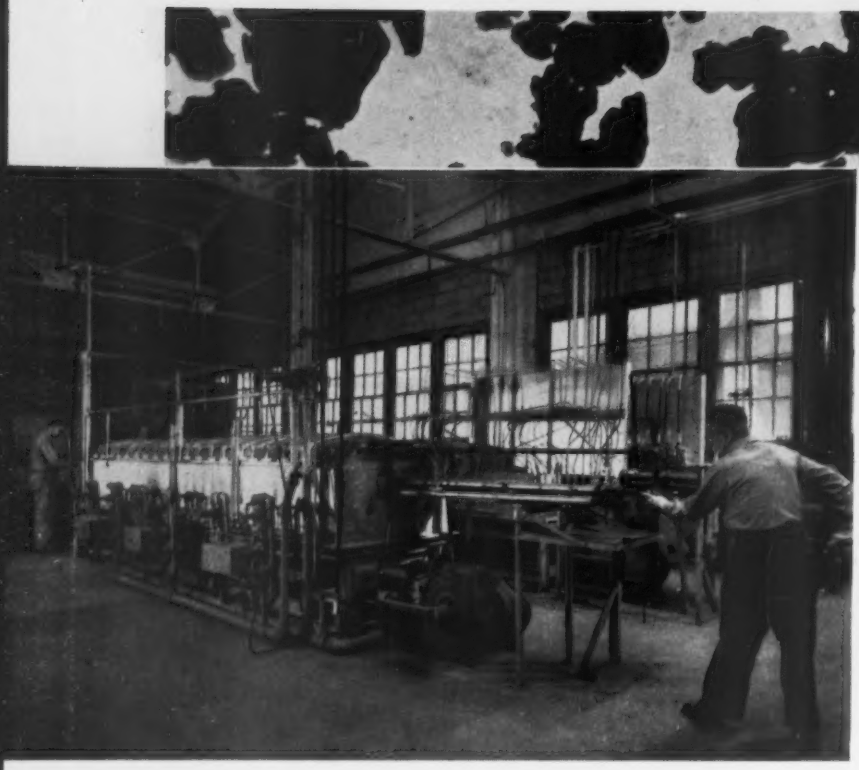


Tungsten in the Lamp Industry

Fig. 1—This gas-fired hydrogen furnace is used in the reduction of tungstic oxide to tungsten. The oxide is loaded in boats and pushed through the heated tubes. Hydrogen gas is passed through the tubes in the direction opposite to the flow of the boats. The photomicrograph above illustrates the resultant tungsten.

ALTHOUGH THE lamp industry uses but a few hundred tons of tungsten a year, this tough metal is truly the heart of the industry. It is the only metal known that can fill the job as a lamp filament to the standard required.

Basically the metal has many properties that are ideal for the lamp applications. It has the highest melting point of any metal (about 3400 degrees C); it is the hardest metal known; and it has tensile strengths of 600 000 pounds per square inch at small diameters. However, obtaining the metal in its pure form and in suitable wire shape for filaments is by no means a simple task.

Production of Tungsten Wire

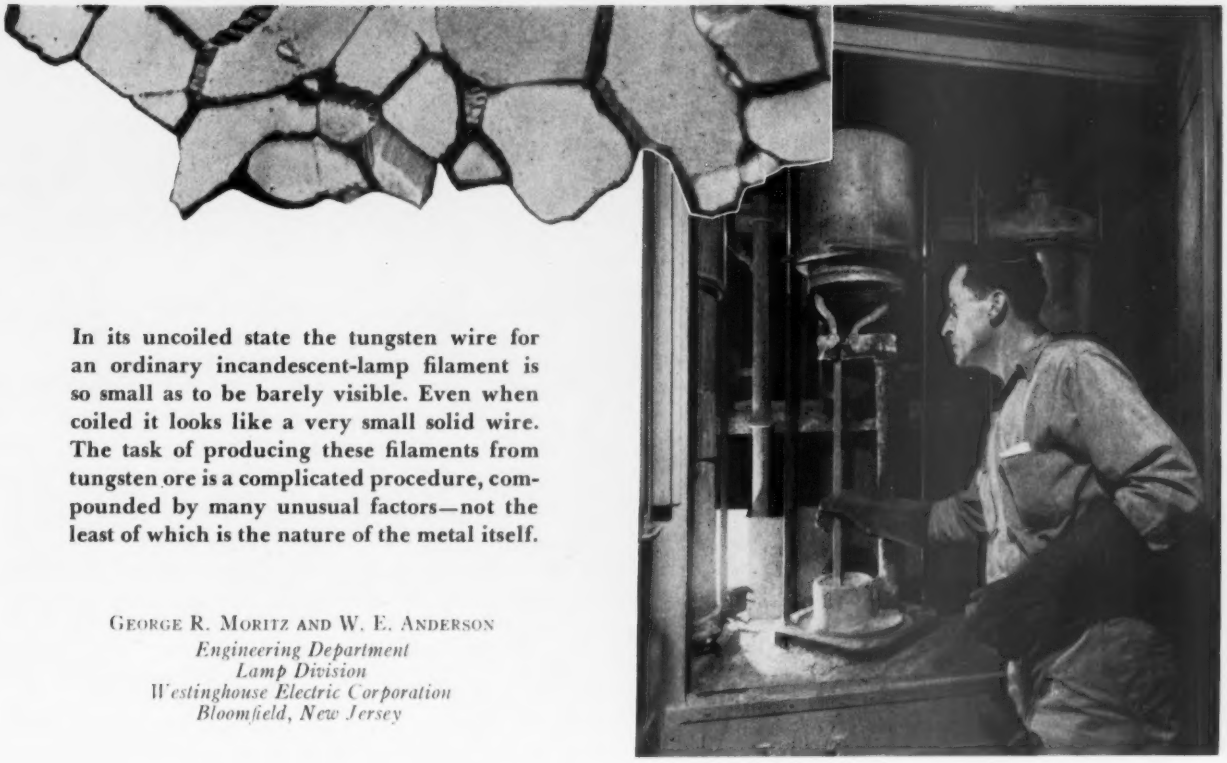
Filaments consist of minute and accurately wound wire. Often an initial coil is made and that in turn is wound into a second coil. Sometimes, it's even carried a step further and the second coil (coiled-coil) is wound into a third. Obviously, filament wire must be malleable and ductile. Yet, if the filament sags from its fabricated shape, efficiency is lessened. Hence it must be strong and non-sagging. In addition, the wire must have a high melting point, be vibration resistant, have a high resistivity, and a low vapor pressure.

Fortunately, tungsten has most of these properties. It has a high melting point; its resistivity is almost directly proportional to temperature; its tensile strength increases as the diameter decreases; it has a general resistance to the effects of high temperature; and it possesses a low vapor pressure at elevated temperatures. Other characteristics of tungsten have been engineered to meet the demands of filament wire for lamps.

The chemical processes involved in the production of tungsten for filament wire are largely concerned with obtaining pure tungsten powder. Filament wire with the desired crystal structure to resist sag and yet ductile is formed by powder metallurgy and treating methods.

Manufacture of wire consists roughly of the following

Fig. 2—The tungsten powder is pressed into an ingot. This worker is leveling the powder in a mold prior to the pressing operation.



In its uncoiled state the tungsten wire for an ordinary incandescent-lamp filament is so small as to be barely visible. Even when coiled it looks like a very small solid wire. The task of producing these filaments from tungsten ore is a complicated procedure, compounded by many unusual factors—not the least of which is the nature of the metal itself.

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successive operations: (1) purification to tungstic oxide (WO_3); (2) reduction of tungstic oxide to pure metal powder; (3) pressing of metal powder into ingots; (4) treating or sintering the ingots in a hydrogen atmosphere by means of electrical current; (5) swaging the square ingots to partially round bars; (6) drawing into wire; (7) annealing at various stages to relieve work strains; and (8) cleaning the wire in a hydrogen atmosphere with heat.

Purification of tungsten ore is unique in that it is not done in the usual manner of melting the ore and removing the impurities as a slag. Because of its high melting temperature it cannot practically be melted in crucibles. Carbon crucibles would withstand the temperature but would contaminate the tungsten. It therefore becomes necessary to use a combination of chemical purification followed by furnace reduction to metal powder. This procedure must be quite meticulously carried out since small quantities of impurities such as tantalum, columbium, arsenic, or phosphorus have a decided effect on its properties and make working of the metal into wire an impossibility.

The tungsten ore, in the form of coarse brown particles, is first chemically analyzed to check the tungstic oxide content and to test for the many impurities that may be present. Having fulfilled the specification analysis requirements, the ore is ready for purification.

Digestion—The first stage in the manufacture of metallic tungsten is the separation of the WO_3 from the gangue materials. Extraction with caustic alkali is a major method and the one used by Westinghouse. The ore is pulverized so that all of it passes a 100-mesh screen. Calculated amounts of water, ore, and potassium hydroxide are added to a large steel tank or digestor supplied with an agitator and heated by gas. The process of getting the tungsten in solution by heating and agitating requires several hours. Water is added from time to time to prevent the resulting potassium-tungstate solution from crystallizing upon cooling. After complete dissolution has taken place, this solution is decanted. Most of the impurities settle to the bottom of the tank as a sludge while the top liquid contains the tungsten in solution as potassium tungstate. Small amounts of iron, molybdenum, calcium, aluminum, and silicon may also be in the solution.

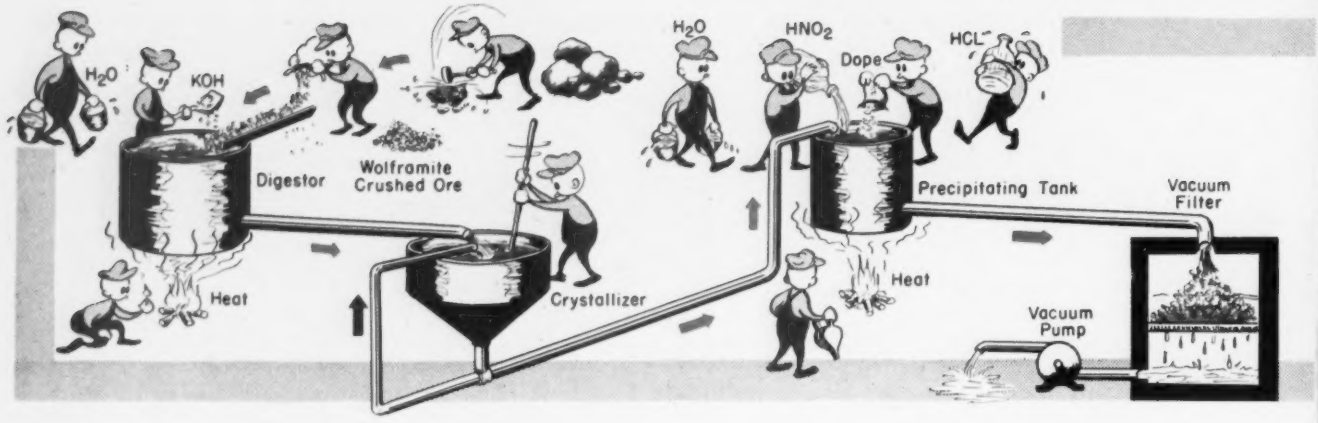
Fig. 3—The pressed ingot is sintered by passing a high current through it. Here it is being inserted between the copper electrode at the top and a mercury pool. The mercury pool prevents breakage by allowing the ingot to move while it is shrinking. Inset photomicrograph shows the tungsten at the end of the process.

Crystallization—The clear potassium-tungstate solution is then filtered and crystallized in another steel tank where it is heated and agitated. Crystals of potassium tungstate form at a specific concentration and settle to the bottom of the tank. Several such crystallizations are usually necessary before the desired pure white crystals of potassium tungstate are obtained. The crystals are separated from the liquid (mother liquor) by filtering, dissolving in water, and pumping into a rubber-lined tank for the next step—precipitation to tungstic acid (H_2WO_4).

Precipitation comes about when the hot potassium-tungstate solution is added to hot hydrochloric acid and water in the precipitating tank. A steam jet is used to heat the liquid to about 80 degrees C. Constant agitation assures a more complete precipitation of the tungstic acid.

The precipitated tungstic acid is very temperamental. It can be affected by temperature of solution, order of addition of acids, concentration, time of precipitation, and the rate at which the potassium tungstate is added to the acid. These variables are, of course, kept constant.

At the end of precipitation, nitric acid is added to pre-



vent the solution from going colloidal. The canary-yellow precipitate of tungstic acid is decanted and given six water washes. After the washing, intentional additions of foreign material are made. These additives, or so-called "dopes," consist of small percentages of either potassium chloride (KCl) and potassium silicate (K_2SiO_3) to produce a non-sag tungsten filament, or quantities of a thorium nitrate [$Th(NO_3)_4$] to produce a vibration-resistant filament. The doped tungstic acid is subsequently dried in preparation for the reduction to metal powder. Such drying, of course, results in dehydration of the acid to tungstic oxide.

The oxide is reduced to the metal powder by passing hydrogen gas over it. This is done in a hydrogen furnace in a continuous flow. The oxide is loaded into iron, nickel, or molybdenum boats, which hold several hundred grams, and passed through long metal tubes. Hydrogen is made to pass through these tubes and they are heated either electrically or by gas furnaces.

A two-stage reduction is generally used to obtain a more uniform product. The furnace has three zones. At the first reduction, the temperatures range from 600–750 degrees C, producing a mixture of partially reduced metal powder and completely reduced powder. The second reduction takes place at a gradient of 650–850 degrees C. The fineness of the resultant metal powder is dependent on temperature of reduction, stoking time, hydrogen flow, and depth of oxide in each boat. The particle size of the tungsten powder for use as filament material may range from 0.1 to 8 or 10 microns.

Pressing—Once the powder has been obtained, powder metallurgy methods are used to get a tungsten ingot. Interestingly, tungsten was one of the first metals to use powder metallurgy as an adjunct to its purification processes.

The metal powder obtained from the final reduction process is thoroughly blended, sieved, and hydraulically pressed into a rectangular ingot. This ingot is made by pressing the powder in a steel mold under 15–20 tons pressure. The resulting ingot is fragile and lacks any definite crystal structure. Preheating the ingot in a hydrogen furnace at a temperature of 1000–1100 degrees C for an hour supplies sufficient strength to permit subsequent handling.

Treating or Sintering—The next step is, of course, to produce the desired crystal structure in the ingot. The first advance towards this structure is the sintering or treating operation, which consists of passing a high current through the pressed ingot while it is suspended in a hydrogen atmosphere. The ingot is suspended between a fixed contact and a mercury pool in a hydrogen-filled, water-cooled metal envelope. The current used is 2500–3000 amperes. The ingot is thus treated to within ten percent of its fusion current and consequently becomes a crystalline metallic bar of virtually pure tungsten. At this high temperature, most of the remaining impurities are eliminated. A shrinkage of the ingot of about 10–15 percent takes place during this electrical heat-treating operation.

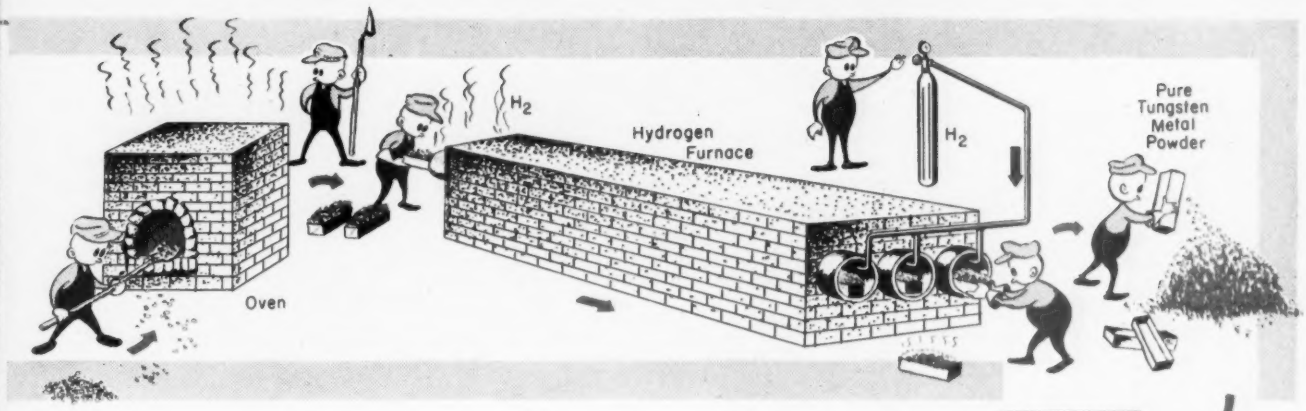
Swaging—The ingot is strong but brittle at room temperatures and must be heated to about 1600 degrees C in an electric furnace in a hydrogen atmosphere before it can be worked (swaged). Swaging essentially consists of inserting the heated ingot between rapidly rotating hardened-steel hammers. These hammers, which deliver 10 000 blows per minute, round and elongate the ingot. Continued swaging to smaller diameters gives rise to the development of a large fibrous structure, which in turn imparts ductility and toughness to the rod. Each time the rods are swaged they are heated prior to swaging. The rods are subjected to decreasing sizes of swaging hammers until they are reduced to 0.090 inch in diameter.

Drawing—The drawing operations consist of lubricating the wire with colloidal graphite, applying heat, and pulling through composition and diamond dies. As the diameter of the wire is decreased, the drawing speed is increased and the temperatures are decreased. It is necessary to interject annealing steps during these swaging and drawing operations, thus relieving the terrific strains set up in working the tungsten rod to fine wire. These annealing steps along with the working operations change the fibrous structure to a crystallized grain structure.

Tungsten wire can be drawn to a diameter of 0.000394 inch and must be held to within a diameter tolerance of plus or minus one percent or about four one-hundred thousandths of an inch. These small dimensions are not measured with a micrometer but are determined by weighing a 200 millimeter length of wire.

Tungsten—Its Application in Electric Lamps

About 1.5 percent of the tungsten consumed in this country yearly is used in electric lamps. The bulk of this is used as filament material in incandescent lamps, the remaining as supports for the filament, as seal wire for lead-in conductors in hard-glass lamps, and as heater elements for electrodes in gas- or vapor-discharge lamps. In these applications, the greatest use is in the form of round wire, ranging in diameter from about three ten-thousandths of an inch to approximately fifty thousandths of an inch. A comparatively insignificant amount is used in the form of flat ribbon.



Drawn Tungsten Wire to Coiled Filament

In making a coiled filament from tungsten wire there are four main steps: (1) the coil-winding operation on a mandrel; (2) baking or coil setting; (3) cutting coils to length; and (4) dissolving the mandrel.

The most common method of forming coils or helices is to wind continuously the tungsten wire on either iron or molybdenum mandrel wire. Coils for the general-lighting-service lamp are usually wound continuously, while for other lamps the coils are wound in sections. Some filament coils are wound with as many as 2100 turns per inch, which means that the spacing between coils is slightly less than one two-thousandth inch and none of the turns must touch or even vary perceptibly in spacing.

The wound coils are then baked on the mandrel in a hydrogen-atmosphere electric furnace to relieve strains set up during the coiling and thus give a permanent set to the coil, so that on removal of the mandrel the coil will remain as wound. Continuously wound coils must be cut to the required lengths before dissolving the mandrel wire.

The mandrel wire is removed from the coil by dissolving in acids that do not attack tungsten. The coils are thoroughly washed successively in water and alcohol and then dried.

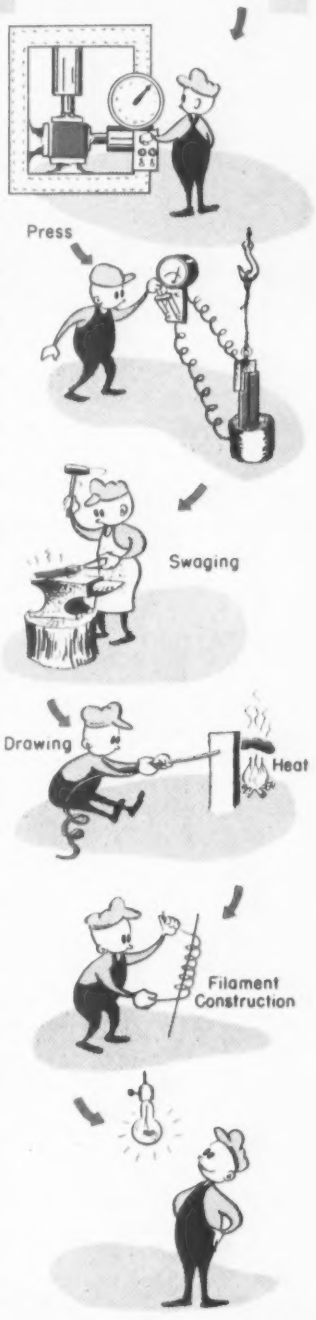
The coils, after a thorough inspection for lengths, uneven winding, and surface defects, are ready to be mounted in lamps. The tungsten coil is "flashed" during the lamp assembly operation, which is performed on a lamp machine. Flashing consists of a step increase in voltage through the filament until the operating voltage of the lamp is reached. This treatment develops a crystal structure in the filament that is instrumental in preventing sagging.

Some Coiling Considerations

Practically all lamps require tungsten for one or another function. In incandescent lamps tungsten, in the form of either single-helix or double-helix (coiled-coil) coils, constitutes the light-emitting filament. In other types of lighting, such as fluorescent or mercury vapor, tungsten is an electron-emitting element for exciting light from gas or vapor. The single helix is made by winding the wire on a mandrel with a spacing between turns of from two to eight tenths of the diameter of the wire; and on a mandrel ranging in diameter from 1½ to 5 times the diameter of the filament wire. This primary coiled mandrel is then wound on a second mandrel; then the mandrels are removed either by mechanical or chemical means.

The fundamental object in coiling filaments is to take advantage of the interchange of radiant energy between adjacent turns of the wire and to reduce the surface cooling (particularly as regards gas-filled lamps). This obtains the maximum efficiency in light production in terms of lumens per watt, for the length of time the lamp is expected to burn. The life in hours of a tungsten filament is approximately inversely proportional to the seventh power of the efficiency.

The first tungsten-filament lamps were of the vacuum type with the straight (not coiled) wire draped over the supporting structure in squirrel-cage fashion. A vacuum was necessary to prevent rapid oxidation and consumption of the filament when it was raised to incandescent temperatures. On the other hand, at reduced pressure, the tungsten evaporated at an increasingly rapid rate as the temperature was raised, and condensed on the inner surface of the glass bulb. This not only caused the light output from the filament, when burned at a constant voltage, to diminish rapidly with time, but also increased the absorption of the light as the deposited film of condensed tungsten on the bulb became more



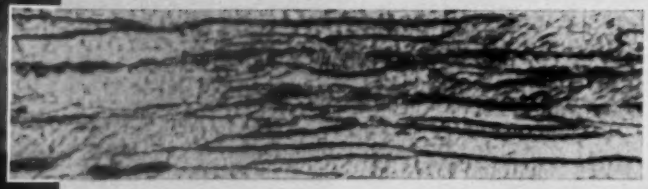


Fig. 4—The first step in making wire from the treated ingot is hand swaging. Mechanical swaging follows. The photomicrograph above shows the tungsten structure after completion of this process.

dense. Although ways were devised to diminish the effect of light absorption, it was not until the principle of applying a counter pressure on the filament—thus repressing the evaporation at the source—was developed, that the so-called lumen maintenance was substantially improved. This was accomplished by filling the lamp with a gas, such as nitrogen (and later argon) that was inert to the hot tungsten. But the gas also had a cooling effect; it was found that coiling the filament greatly improved the initial efficiency of the lamp for a given life and the lumen output throughout its life remained more nearly constant.

Fortunately, the necessity for coiling the filaments did not appear until after drawn tungsten wire, with its greatly improved ductility, was developed. This took care of the mechanics of forming the coil and getting it mounted within the lamp. After it started to burn, however, the turns gradually opened up and the coil sagged as the result of gravitational pull. If this could be prevented, even greater improvement could be had in efficiency as well as lumen maintenance. Research as to the cause of this tendency to sag disclosed that the thorium oxide, product of thorium nitrate added as an original ingredient to prevent "off-sets" in the filament, in turn tended to promote sag when the filament was coiled and raised to operating temperature. The thorium oxide retarded crystal growth after the tungsten recrystallized out of its drawn fibrous structure, and increased the vibrational strength when brought up to the operating temperature of the filament. A change in this "dope" (i.e., using potassium chloride and potassium silicate instead of thorium nitrate) not only promoted crystal growth, but also influenced the shape in such a way that the crystals became interlocking and supported each other against dislocation by gravity when hot. Not only did this solve the sag problem but also improved the ductility of the cold wire to the point where it could be wound into coils without auxiliary heat applied to the point of winding on the mandrel.

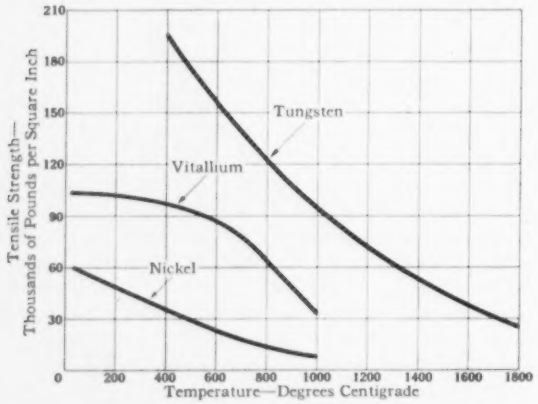


Fig. 5—A comparison between the tensile strengths of tungsten, vitallium, and nickel at different temperatures.

To give some idea of the effect on lamp efficiency of coiling the filament, as a result of interchange of radiant energy between turns in vacuum, Table I is of interest. This shows the effect, in terms of percent of the efficiency of an uncoiled filament, of various mandrel and pitch ratios for filaments operated at the same current.

The same table shows the approximate effect produced in a gas-filled lamp by two commonly used gases; also the percentage effect of double coiling is indicated. All filaments are of the same diameter, operated at the same current.

In studying these relationships it must be remembered that the wire diameter and input current are constant, and that any increase in interchange of radiant energy, or loss due to the cooling effect increases or decreases the temperature of the filament. Since the burning life of the filament is inversely proportional to the maximum temperature of any one spot along its length, the life of the lamps at these efficiencies varies accordingly. To absorb the increase in energy due to coiling and have the filament remain at the same temperature, a decrease in current density, or, conversely, an increase in the filament wire diameter is necessary. Similarly, an increase in current density or decrease in filament-wire diameter is necessary to compensate for the cooling effect produced by a gas.

Filament Requirements

Coiled filaments must also be arranged in different forms within the lamp, depending on the service for which the lamp is designed. For example, in general-lighting lamps the primary requisite is that the filament, mounted on its supporting structure, can be inserted easily through the neck

of the bulb; this, in turn, is dependent on the type of socket in which the lamp is to be used. On the other hand, coils in lamps to be used for beam projection, either in optical systems or reflectors, must be concentrated as much as possible. This introduces additional effects of interchange of radiant energy between different sections of the coil. All of these effects, as well as those due to the kind, volume, and pressure of the gas used in gas-filled lamps, determine the diameter of a filament for a given current and efficiency rating as well as the length corresponding to a predetermined voltage rating for the lamp.

These factors are combined into two constants, M and C, in the formulas:

$$D = MA_{BE}^{\frac{2}{3}}$$

Diameter equals M times amperes at a basic efficiency (BE) raised to a two-thirds power.

$$L = CMV_{BE}A_{BE}^{\frac{1}{3}}$$

Length equals C times M times volts times amperes raised to the one-third power, both the volt and ampere values being at a basic efficiency.

To reduce the current and voltage to a basic efficiency—10 lumens per watt for vacuum lamps as representing general average for this class, 16 lumens per watt for gas-filled lamps—volt-ampere and volt-lumen characteristic curves have been accurately determined.

Consequently, numerical values for the two constants (M, C) are a function of the overall design characteristics of each specific lamp—the mandrel and pitch ratios of the coil as determined by the shape and source dimensions required, the light source and bulb dimensions as determined by the service, the gas filling (or absence of gas) as determined by the wattage, voltage, light-source dimensions and efficiency, and the efficiency as determined by the service life expected. These values must be determined experimentally for each new lamp design except when the new lamp is closely related to a previous design or the lamp engineer has considerable experience in the interrelationships of these fundamentals.

As mentioned earlier, the kind of gas used in gas-filled lamps has considerable influence on the efficiency of the lamp. The lower the thermal conductivity and convection losses of the gas, the less the cooling effect on the filament. This should logically lead to the use of a gas with a minimum of these characteristics. Such gases exist. The so-called noble gases—argon, krypton, and xenon—are inert to tungsten at filament operating temperatures, and have decreasing conductivity and convection losses in the order named. Unfortunately, however, for incandescent-filament lamp use, they also have a decreasing ionization potential and are limited as to commercial availability in the same order. (The ionization potential of a gas is the voltage drop through which an electron must fall freely to remove an electron from the atoms. This is a necessary condition for rendering the gas conductive to the flow of electricity.) However, argon has largely displaced nitrogen as a gas filling in all but the higher voltage concentrated-filament lamps where arc-over tendencies are prevalent. Even so, it cannot be used in absolutely pure form but must be blended with nitrogen in various ratios, depending on the arc-over characteristics of the particular filament lamp design.

During the past few decades, lamp engineers have learned much about tungsten's idiosyncrasies and have applied their results to filament making—but there still remains room for improvements. Greater ductility, for example. A tungsten wire with greater hot-strength, and which will develop a stronger non-sag grain structure when burned in a lamp is also desirable. And although much time and effort have been devoted to the wire-drawing process, there is still opportunity to improve it to obtain better uniformity in diameter and ductility. Another possibility, of course, always lies in design improvement in the lamp and filament themselves, rather than specifically in the metal.

Fig. 6—A group of completed filaments mounted on glass bases. All are of the single-helix type.

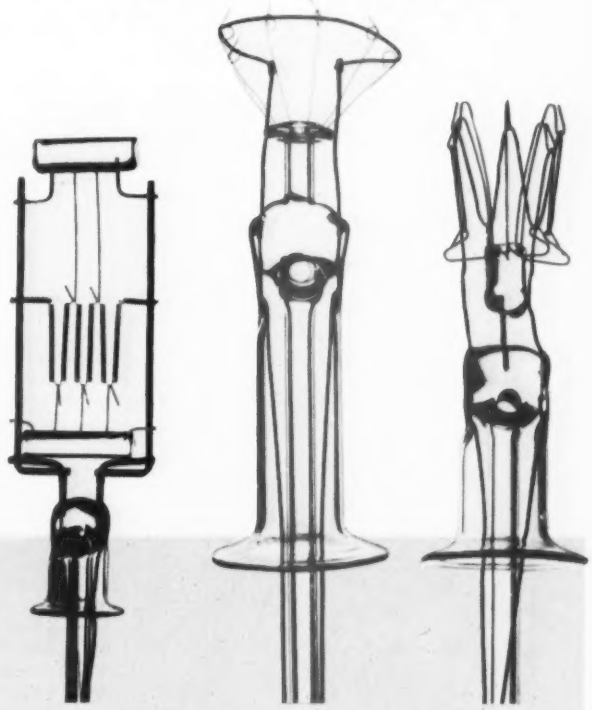


TABLE I—EFFECT OF FILAMENT COILING ON LAMP EFFICIENCY

Filament	Gas	Percent Mandrel[1]	Percent Pitch[2]	Comparative Efficiency
Not coiled	Vacuum			100
Single helix	Vacuum	500	180	112
Single helix	Vacuum	500	150	127
Single helix	Vacuum	200	150	156
Single helix	Vacuum	200	120	195
Not coiled	Nitrogen			40
Single helix	Nitrogen	200	150	50
Single helix	Argon	200	150	70
Single helix	Argon	500	150	90
Coiled coil	Argon	200/200	150/150	135

[1]Percent mandrel is the ratio of the diameter of the mandrel to that of the filament times 100, i.e.,

$$\frac{d_m}{d_f} \times 100 = \text{percent mandrel}$$

[2]Percent pitch is the ratio of the pitch of the wound coil (distance between turns) to the diameter of the filament times 100, i.e.,

$$\frac{P}{d_f} \times 100 = \text{percent pitch}$$

TABLE II—PROPERTIES OF TUNGSTEN

Melting point	3410±20 deg C
Rate of vaporization at 2500 deg K	9.18×10^{-10} grams/cm²/sec
Rate of vaporization at 3000 deg K	9.92×10^{-7} grams/cm²/sec
Resistivity at 28 deg C	5.64 microhms/cm³
Resistivity at 2500 deg K	77.25 microhms/cm³
Resistivity at 3000 deg K	96.2 microhms/cm³
Normal brightness at 2500 deg K	237.5 candles/cm²
Normal brightness at 3000 deg K	1257 candles/cm²
Color temperature at 2500 deg K	2557 deg K
Color temperature at 3000 deg K	3094 deg K

Insulation Impulse Strength of High-Voltage Generators

RECENT studies of the ground-wall insulation of large high-voltage generators demonstrate that its impulse strength is considerably greater than hitherto believed. This fact provides a comfortable margin between the insulation strength and the maximum surge voltages permitted by the applicable lightning arresters. Furthermore, it indicates that large single-turn machines can be exposed to higher voltages than have been believed safe, thereby extending the range of conditions under which specific surge-protection equipment is not required for generators.

The impulse strength of machine insulation is usually considered as equal to, but no greater than, the crest of the 60-cycle proven strength of the insulation as demonstrated by the one-minute standard factory dielectric proof test for new windings (ASA-C 50). In certain cases, this value and the possible maximum voltage permitted by the applicable lightning arresters did not coordinate on paper, although field experience has been quite satisfactory. For example, the impulse strength of the ground wall of a 13.8-kv machine would be, on the above basis, 40.2 kv. A typical station-type arrester designed for machine protection has a maximum characteristic of 46 kv on sparkover and 45 kv on discharge voltage. While the average of a number of arresters is less than this, the possible maximum figure is in excess of the 40.2-kv value predicated for the impulse strength of the ground wall. Much additional data have been made available by recent tests on conventional mica insulation used on the machine windings. The voltage-endurance characteristics of such insulations are now known, so that it is not necessary to adhere to pessimistic concepts of the impulse strength of the basic ground-wall generator insulation.

Comprehensive tests have been made to (1) study the behavior of machine windings when subjected to surges, (2) determine the actual impulse strength of the insulation, and (3) demonstrate the ability of winding insulation to withstand impulse voltages.

The determination of the actual impulse strength of the ground insulation is the simplest, yet perhaps the most important phase of the problem. Industry application and protection methods are directed toward suppressing surge voltages and holding them below a certain level. It is, therefore, important to have information as to the actual impulse strength obtainable on commercially produced machines and to be able to demonstrate the existence of this impulse level without damaging the insulation.

The determination of the actual strength of standard ground-wall insulation has contributed greatly to increased confidence in the impulse level of modern machine windings. Impulse breakdown tests have been an important part of the study of the voltage endurance of several kinds of mica insulations; these have been based upon statistical studies covering the range from 1½ microsecond front impulse waves to very long-time step-by-step breakdown tests. The results show a rational relation between the short-time and long-time breakdown voltage levels.

These studies show that the voltage-endurance curve of mica insulations indicates at least 10-percent increase in insulation level for a decrease in time of voltage application by

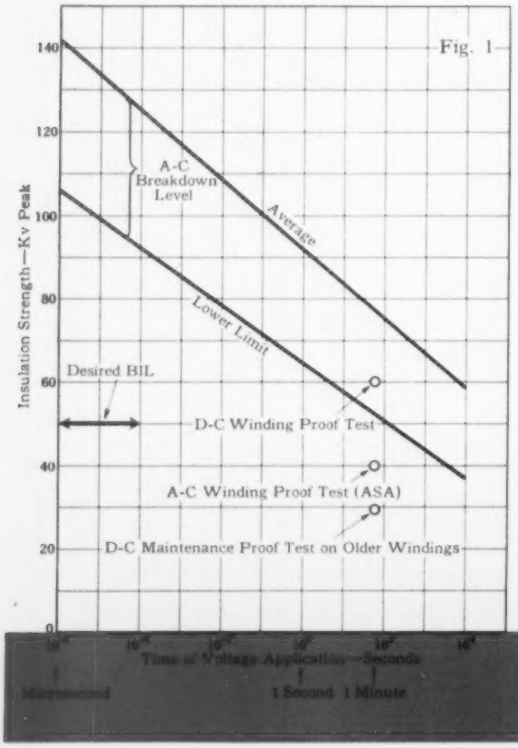


Fig. 1—The a-c breakdown levels of a typical high-voltage insulation.

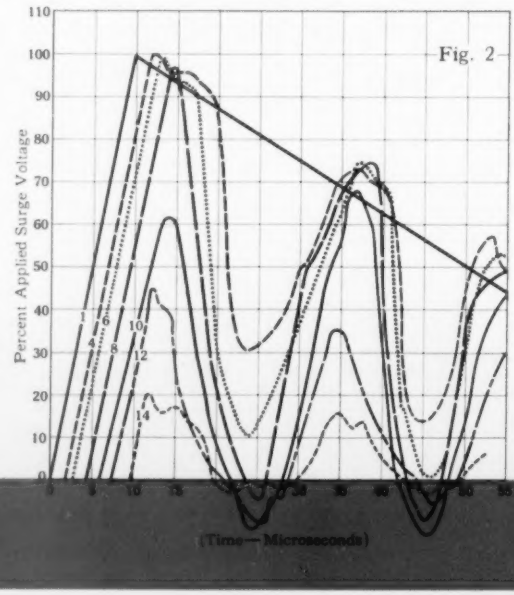


Fig. 2—These are oscillations that would overstress turn insulation. Numbers on the curves indicate the voltage to ground at that point in the test winding.

The impulse strength of the insulation for large generators is obviously a factor of great importance to both the user and the manufacturer. Recent extensive tests reveal a far more accurate picture of its true strength.

GRAHAM LEE MOSES, *Manager, Development Insulation Sec., Generator Engineering Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.*

10 to 1. Therefore, for a 30-percent increase of the impulse level over the one-minute peak value, the cumulative surge time to failure should be about 1/1000 minute or 60 000 microseconds. In correlating the voltage-endurance data with the fact that the ground-wall insulation has withstood the one-minute ASA proof test, it can be concluded that this insulation will withstand many impulses of 100 microsecond duration whose voltage peak does not exceed the peak of the one-minute proof test by more than 25 percent. This has also been demonstrated by tests on insulation specimens.

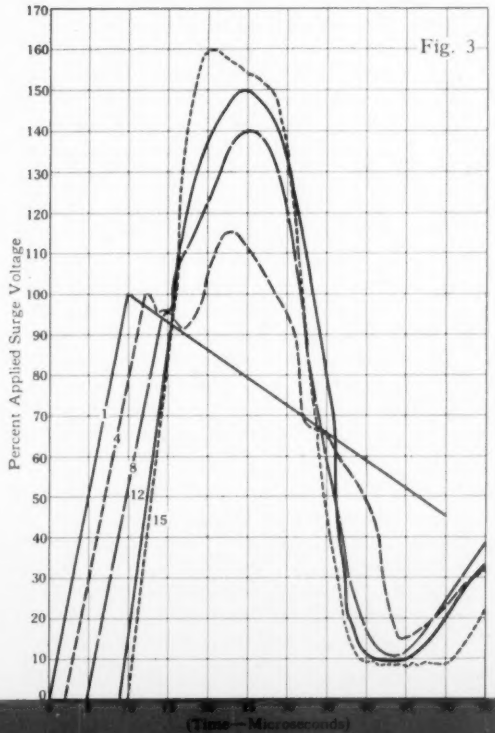
Studies of the d-c dielectric strength of insulations have made an important contribution to the knowledge of their impulse strength. This has demonstrated that the time of d-c voltage application is far less significant than the time under a-c stress. But it further shows that a d-c proof test can demonstrate the ability of mica insulation to withstand an impulse of equal magnitude.

Some of the factors involved are summarized in Fig. 1. This illustrates an approach to the problems associated with coordinating the impulse level of machine windings with single-turn coils. The a-c breakdown levels of a typical high-voltage insulation in the 13.8-kv class have been plotted as a voltage-endurance curve showing average breakdown level and the statistical lower limit of the range (average minus three times the standard deviation). The insulation used for this example is not the best of the modern types, but is an older insulation widely used for more than 20 years. The newer synthetic-resin impregnated mica insulation (Thermalastic) has greater dielectric strength at any point on the time scale and, therefore, presents an even more favorable picture in this respect.

As can be seen, the value of the final a-c proof test of the winding required by ASA-C 50 is below the lower limit of the insulation breakdown. Above this point is the d-c proof test that is normally applied to the winding by Westinghouse during manufacture, but after the completion of all assembly work so that no winding damage will occur. The desired impulse level* for coordination with conventional surge protection is shown as a range from one microsecond to 100 microseconds at the 50-kv peak level. The impulse level desired is somewhat below the lower limit of the insulation (for one minute) and well below the d-c proof test (one minute) that is currently being applied to such windings. The slope of the voltage-endurance curve and the displacement of the points on the time scale indicate the importance of this concept because the voltage breakdown level is related to time. This d-c proof test of itself gives adequate assurance that such single-turn windings employing this insulation have an impulse level at the desired value of 50 kv or above.

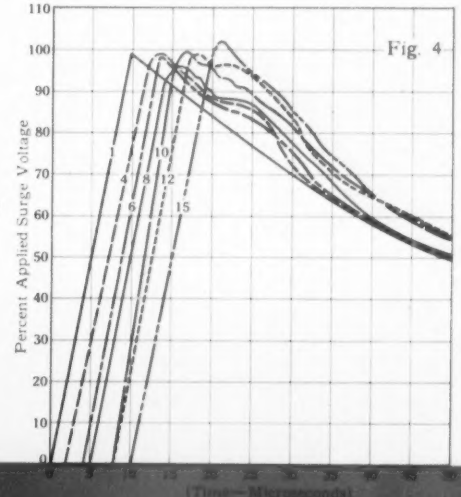
Impulse testing of windings is complicated by the possibility of reflections and oscillations. These can result in higher stresses than the incident surge and can seriously overstress both the ground and turn-to-turn insulation (in the case of multi-turn windings). The steepness of the incoming wave-

*The term "impulse level" used herein regarding generator winding insulation is defined as the crest voltage of the impulse wave that the ground insulation is capable of withstanding when new. In the absence of a standard definition of wave shape for generator insulation, a ten-microsecond wavefront is assumed.



← **Fig. 3—Serious overstressing of ground insulation by reflections. Numbers again indicate voltage to ground at that point in the generator test winding.**

→ **Fig. 4—A suitably matched terminating impedance means there are no damaging reflections or oscillations.**



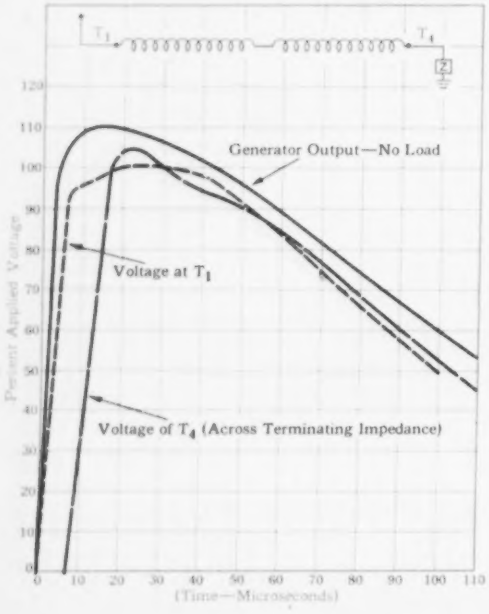
front determines voltage distribution on multi-turn coil windings. Very steep-fronted waves can concentrate the complete voltage of the impulse across a few turns, thus overstressing the turn insulation. However, where the wavefront has been sloped to ten microseconds or more, the impulse voltage can be distributed over several turns to reduce the stress to within the level of conventional turn insulation. In the past a high percentage of machines employed multi-turn armature coils and the problem of protecting turn insulation always had to be considered. Now large turbine-generator designs have single-turn coils, where every turn of the winding has complete ground insulation.

Comprehensive tests were made on simulated windings on a calculating board, and actual windings at low voltages, followed by high-voltage impulse tests on the complete winding of a 60 000-kw turbine generator for 13.8-kv operation.

All these methods checked each other and the behavior of simulated windings corresponded to that of actual machine windings when both low- and high-voltage surges were applied. The behavior of all was predictable from measurable constants from a simple theoretical approach. This provides a basis for avoiding dangerously high concentrations of impulse voltage or reflections and oscillations when impulse testing at high voltages.

The results of these tests can best be summarized by four curves produced from oscillograms. The results of oscillations that overstress turn insulation are shown in Fig. 2. Serious overstressing of ground insulation by reflections is shown in Fig. 3. Both are the result of improper selection of terminating impedance of the winding under test. Testing a winding with a suitably matched terminating impedance permits stressing the ground insulation at the desired level without reflections or oscillations, as is indicated in Fig. 4. The impulse wave moves through the windings as desired. It is of interest to note the electrical length of the winding on Figs. 2, 3, and 4. This is the time delay between the entry of the surge at one end of the winding and its exit at the other end (ten microseconds in this case). The same phenomena on the winding of a 60 000-kw, 13.8-kv turbine generator when tested at 50 kv is shown in Fig. 5. In this case the electrical length is eight microseconds.

Fig. 5—The time delay of a winding of a 60 000-kw, 13.8-kv turbine generator tested at 50 kv.



In the tests the windings were separated at the neutral, and the voltage distribution differs from that obtained in service with the windings connected at the neutral. Voltage distributions shown for a given terminating impedance should, therefore, not be interpreted as applying to generators grounded through that resistance, particularly when connected through transformers to the high-voltage system. The pertinent observations relating to problems encountered in applying actual surges to generator windings under test were:

1—The maximum voltage observed in a winding with an ungrounded end terminal can be twice that encountered when the end terminal is grounded.

2—Seriously distorted voltage distributions can occur within the winding during impulse testing, depending upon the impedance of the terminal resistance.

3—The resultant voltages and oscillations are predictable by calculating-board studies employing lumped constants, because the phenomena are similar to those occurring on short transmission lines subjected to similar impulses.

4—The impulse-voltage distribution can be predetermined at low voltage on the actual winding by employing repetitive surge-testing equipment.

5—During impulse testing, overvoltages due to reflections and oscillations can be avoided by suitable control of the generator test conditions.

6—The wavefront of the incoming test surge voltage should be suitably sloped. The industry practice of using a ten-microsecond wavefront appears acceptable as a test value.

7—During impulse tests, the winding should be terminated through a resistance that is reasonably close to the surge impedance of the winding, in order to limit the maximum voltage within the winding to the level of the applied voltage. (This applies to the test procedure only, not to application.)

8—Single-turn coil windings, when terminated in the proper impedance, will withstand impulse voltages 1.25 times the peak of the proven insulation strength of the ground wall.

The use of d-c one-minute factory tests (to supplement the a-c ASA tests) at values considerably higher than the suggested impulse level (1.25 times the one-minute a-c test peak value) gives ample assurance of the impulse strength for the ground insulation of generators.

Studies of impulse-voltage distributions on simulated and actual windings demonstrate that large high-voltage generator windings with single-turn coils can withstand impulse test voltages high enough to provide assurance of coordination with the level of protective devices.

Testing techniques and equipment have been developed that permit predetermination of voltage distribution on the actual winding at low voltage, to prevent damage to the generator winding due to reflected or oscillatory voltages.

The procedure developed for single-turn windings appears applicable to multi-turn high-voltage windings, and work on this project is under way.

The industry's experience with large high-voltage windings has been quite favorable, as conventional surge protection has prevented failures from over-potentials. In those few cases where failures from surges have occurred, there were other contributing causes (such as previous damage to the insulation at the point of failure). From this it can be concluded that the present surge-protection practices of the industry are satisfactory, and that the currently used insulations possess adequate impulse levels for the type of surge protection used.

Personalities in Engineering

On March 20, 1952, two switchgear engineers were given special recognition—and a $5000 award each—for their outstanding work in connection with the invention of the multiflow De-ion grid circuit breaker. These were the largest awards of this type ever made by Westinghouse under a plan to reward outstanding inventions, and indicate the unusual significance of their contribution to circuit interruption. One of the two recipients was Dr. W. M. Leeds.

We mention this award for two reasons—because its significance gives some idea of the excellence of Leeds' engineering and inventiveness, and also because his reaction to the award reveals something of his personality. Although tremendously pleased by the honor, Leeds was also deeply concerned; he felt—with sincere modesty—that he was being rewarded for work in which several of his associates had contributed much. And he has done his best, in many ways—including a large dinner party for those concerned—to express his gratitude to them.

Leeds' interest in education, both formal and of the experience variety, is clearly evident; and it is more than a passing interest. He has been influenced by industry's participation in education, and has taken part in it both as a student and as an instructor.

His first interest in electricity came, as is so often the case, via a chance gift, in this instance a child's construction kit containing parts for an electric motor. By the grand old age of 16 he had several years' experience as an electrician's helper, and had wired a house by himself.

Leeds' first contact with Westinghouse came at a time when he was trying to decide where to go to college. The choice narrowed down to a large college widely noted for its engineering curriculum, and a small liberal arts college where he could obtain only the basic courses in electrical engineering. Leeds himself favored the smaller college, but had not quite convinced his family when he came upon an AIEE article written by B. G. Lamme; in it Lamme recommended that a budding engineer should get as broad an education as possible, with the accent on engineering fundamentals. Influenced largely by the article, Leeds overcame all doubts and enrolled at Haverford College near Philadelphia. He still feels that this decision was the right one.

He graduated from Haverford in 1926 with a B.S. degree. The problem of whether to take a year of graduate study in engineering at a large university was solved by an offer from Westinghouse, which meant an opportunity to work toward an advanced degree while employed in industry. This plan was followed through, the result being an M.S. degree from the University of Pittsburgh in 1930. Curiously enough, Lamme's influence was again felt, albeit in an indirect fashion, when Leeds was awarded a Lamme Scholarship in 1937. He spent this year at Massachusetts Institute of Technology studying for his Doctor's degree. Leeds completed all course requirements for the doctorate, but was unable to conclude the research in the time available. He later transferred his credits to the University of Pittsburgh, and was awarded the Ph.D. degree in 1945.

When Leeds came to Westinghouse in 1926, as a member of the Graduate Student Course, he first showed an interest in meters and instruments. However, he soon found himself in the Circuit Breaker Department, where high-power laboratory testing was stimulating a tremendous surge of new development activity.

Leeds considers that the power circuit breaker offers the young engineer as much challenge as any other single device in the electrical field. As he puts it, "It gives you a chance to use physics, a little chemistry, a lot of mechanical and electrical engineering, and even electronics. Where else could you find the opportunity to cover as varied a field as that?"

It is just as obvious that Leeds accepted this challenge and has bent his efforts toward meeting it. As first a member of the Circuit Breaker Development Section, and since 1939 as the manager of development activities, he has played a part in most of the major advances of the past 25 years—a period, incidentally, that saw the maximum rating of circuit breakers grow from 2 500 000 kva interrupting capacity at 230 kv, opening in 1/5 second, to those now being constructed for 25 000 000 kva at 330 kv, opening in only 1/20 second. A further indication of his acceptance of the challenge is the fact that he holds, either by himself or jointly, 48 patents pertaining to circuit breakers.

At one time Leeds wanted to become a teacher. However, the teaching yen has since been satisfied by his work with young engineers, and by the courses in circuit interruption he teaches in the Electrical Design School and the Westinghouse-University of Pittsburgh graduate program. Leeds has thus passed on to young engineers much of the experience he has gained on circuit breakers.

By nature a quiet man, Leeds warms up quickly on the subjects he is most interested in. Obviously closest to his heart are education and arc interruption, certainly apropos for one concerned with development work on circuit breakers.

The Bright Picture of Aluminum

Among the metals, the story of aluminum is pleasantly different. Its future is not shadowed by paucity of high-grade ores. Its price is stable, with future reductions probable. Its alloys are growing in number, quality, and usefulness. Present uses are rapidly increasing, and whole new industrial fields appear to await only enlarged production facilities and time to develop.

ALUMINUM has spent most of its young life suffering from growing pains. And it still is. Growing pains aggravated by sharp, deep—but brief—drops in consumption, climaxing each occasion of world turmoil—military or economic. World War I carried United States' primary aluminum production from a modest 24 000 tons in 1913 to a peak of 69 000 in 1920, followed by a sudden postwar drop (1921) to 27 000. (All figures are in short tons.) The prosperity of the 20's swept aluminum usage to new highs in 1930—115 000 tons, followed by a rapid but brief dip in the early 30's to a low of 37 000 tons. With War II on the horizon, 1938 production climbed to about 143 000 tons, whereupon, with the insatiable demand for military airplanes, production of aluminum was swept up to a wartime peak of 920 000 tons. After a short postwar dip to half this amount, the industry was beginning to catch its breath for a "normal" peacetime growth in usage when the events in Korea set off another scramble for all the metal the industry could produce—and more. A new record high of 937 000 tons of primary aluminum produced in the United States was set last year.

In the world's production of metals, aluminum is exceeded only by iron in volume. In fact, volumetric production of aluminum exceeds that of copper, lead, and zinc combined.

The industry is currently undergoing a huge expansion in production facilities designed to more than double the pre-Korean capacity. Since the summer of 1950, when the capacity of plants in the United States stood at 750 000 tons annually, the government has authorized the construction of 877 200 tons of new capacity through three different expansion programs. The newest program, announced by the Defense Production Administration in October, 1952 will add 214 000 tons, bringing the United States' total productive capacity by the end of 1955 to about 1.7 million tons annually. (The exact figure depends on how much of the high-cost, reactivated capacity is included.) This does not count the 200 000 tons in Alcoa's proposed development in Alaska, which is contingent on international agreements not yet effected, whereby alumina would be reduced with energy made in hydroelectric plants supplied with water imported from Canada.

Composition of the Industry

New aluminum, at present, is produced in the United States by only three integrated companies: the Aluminum Company of America, Reynolds Metals Company, and Kaiser Aluminum and Chemical Corporation. Of the 937 000 tons turned out last year, Alcoa produced about 49 percent, Reynolds 29 percent, and Kaiser 21 percent. The announced expansion program is bringing several new names into the scene. At the outset these newcomers will operate on a comparatively small scale. The Anaconda Aluminum Company is building a plant in Montana to produce 50 000 tons of aluminum, starting with purchased alumina. More recently others have announced plans to build plants. These and their tonnages are: Olin Industries, Inc., 110 000 tons; Harvey Machine Company, 54 000 tons; Wheland Company, 50 000 tons. The domestic aluminum-output capacity in percentage, when the present round of expansion is complete, will be divided as follows: Alcoa, 34.4 percent; Reynolds Metals, 25.0; Kaiser Aluminum, 24.6; Olin Industries, 6.7; Harvey Machine, 3.3; Anaconda Aluminum, 3.0; and Wheland, 3.0.

Until 1940 the sole producers of virgin aluminum in North America were the Aluminum Company of America and the Aluminum Company of Canada. In May, 1941, Reynolds Metals began an integrated operation, having previously been fabricators only, principally of foil. In 1946 Kaiser leased and later purchased, as did Reynolds, aluminum plants built by the government during the war, to which they have since added facilities.

One of the problems of the industry is the physical relationship of processing plants and markets, necessitating a great deal of transshipment. Bauxite from Arkansas, South America, and the Caribbean area is shipped to alumina-producing

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Written by Charles A. Scarlott from information provided by the U. S. Bureau of Mines; Defense Production Administration; The Aluminum Association; and the sales and technical staffs of the Aluminum Company of America; Reynolds Metals Company; Kaiser Aluminum and Chemical Corporation; and Westinghouse.

plants in Arkansas, Alabama, Texas, Louisiana, and Illinois. The need for low-cost electric power to reduce the oxide to the metal requires that the alumina be shipped to plants in Oregon, Washington, Tennessee, North Carolina, New York, Arkansas, and, recently, to Texas and Louisiana where low-cost natural gas for engine-driven generators is available. Later there will also be plants in Montana and, to be decided later, West Virginia.

The Development of the Aluminum Industry

For all of its spectacular accomplishments the aluminum industry is still in its period of early development. Witness the fact that total world production to date has been less than 25 million tons (that is less than two months' world production of pig iron). In the United States commercial production of aluminum in significant amounts did not start until 1888. By 1900 the total aluminum that had been made was about 6000 tons.

Most metals—iron, copper, zinc, gold, silver—can trace their history back to antiquity. Not aluminum. This is because the affinity of aluminum for oxygen is so strong that it could not be broken economically by the methods available to early metallurgists.

Credit for the first isolation of aluminum goes to Hans Christian Oersted—after whom the unit of magnetic feed is named. As professor of physics at the University of Copenhagen in 1825, he produced minute amounts of it by using a chemical process. It was not until 1845 that a German scientist, Friedrich Wöhler, chemically obtained a few milligrams of aluminum and established several of its basic properties. Henri Sainte-Claire Deville, a French chemist, improved the technique of its production by the chemical method and was able to make aluminum on a small commercial scale and sell it for $27 a pound in 1857.

The real break came in 1886. That year Charles Martin Hall made the discovery that is still the basic process for aluminum manufacture. While studying chemistry at Oberlin College in Ohio, Hall had been interested in finding a cheap method of producing aluminum. After graduation he experimented with the production of aluminum in a homemade laboratory in the family woodshed.

His problem was this: alumina—aluminum oxide (Al_2O_3)—could be produced in pure form by comparatively simple chemistry. The difficult task was to break the bond between aluminum and oxygen. Hall believed it could be done with electricity. But, alumina is a white crystalline powder that melts at a high temperature. It could not be electrolyzed directly. He sought a substance that dissolves alumina and has a low melting point. After much searching he hit upon the one that does the trick—cryolite. This is aluminum sodium fluoride (Na_2AlF_6), found in abundance only in Greenland, but is now also produced synthetically. Hall found that passing direct current through a molten electrolyte of alumina and cryolite contained in a carbon crucible produces pure aluminum. Oxygen freed from alumina combines with anode carbon, forming carbon dioxide. Little cryolite is consumed in the process (only 0.1 pound of cryolite per pound of aluminum produced) as it is essentially but a vehicle for the alumina. On this important discovery the aluminum industry rests today.

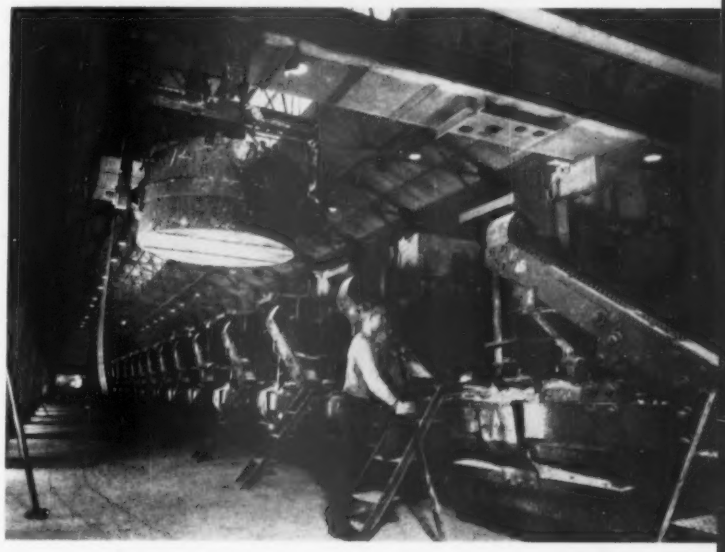
The story of aluminum's beginning would not be complete without relating an unusual coincidence. Hall was but one of many men who had long sought a practical way to unlock aluminum from alumina. Among them was Paul L. T. Heroult of France. Curiously, although Heroult and Hall knew nothing of each other's work, they arrived at identical methods of producing aluminum—and did so within a few weeks of each other. To heighten the coincidence, Hall and Heroult were born in the same year—and died the same year, 1914.

Sources of Aluminum

The world has been generously provided with aluminum ores. Aluminum has been, and will continue to be for some time, derived from a single ore, bauxite (after Les Baux, France). There are many large deposits of bauxite, much of it of good grade. Large ones are in France, Hungary, Italy, Yugoslavia, Greece, the Gold Coast and French Guinea in Africa, Malaya, India, and Indonesia. In the Western Hemisphere, Arkansas, the Caribbean area, and the northern states of South America have the principal known bauxite

Tray-thickener tanks where final clarification of liquor is done in the Mobile, Alabama, works of Aluminum Company of America.

Electrolysis of alumina in cryolite produces molten aluminum. This "pot" room is in the Jones Mills, Ark., plant of Reynolds Metals.



bodies—and these are adequate to support American and Canadian production for decades—assuming a generous but not fantastic growth in consumption. Large tonnages of bauxite have come from British Guiana and Suriname (Dutch Guiana) in South America. Surprisingly it was not until 1942 that large deposits of readily accessible bauxite ores were discovered and are now being mined in Jamaica. Smaller but important ones have been located in Haiti and the Dominican Republic. These have the further advantage of being less than half as far from Gulf ports as are the Guianas. Bauxite ores of Brazil are extensive but relatively unexploited. Quite probably other large bauxite bodies lie undiscovered in these or adjacent areas or in regions more remote and less accessible. Present reserves are so large that incentive or need for exhaustive search for ores more difficult to reach has been lacking.

In the United States the only major deposits of bauxite are in Arkansas. These, in terms of the long-range need, are not large, particularly of the high-grade variety. For some years Arkansas has not supplied more than a portion of the raw ore for United States' plants. Georgia has small bauxite bodies. The United States definitely is not self-sufficient as to bauxite. Canada has none.

In addition to bauxite, there are other aluminum-bearing materials that are a potential source of alumina. High-alumina laterite, approaching low-grade bauxite in composition, exists in northwestern Oregon and southwestern Washington and is extensive in amount.

Clays containing about half as much alumina as bauxite are available in the United States and elsewhere. Four experimental plants were built to win aluminum from non-bauxitic ores, but only one is now in use. Processes are known by which aluminum can be won from clays and other ores, such as anorthosite and alunite, but none is attractive while bauxite is available in ample quantities and at present costs. But, come the day when good and even fair bauxite becomes scarce or rises significantly in price—and that day eventually will come—producers will turn to clay sources. Perhaps, when the need arises, better recovery methods will be had. In short, aluminum, unlike so many basic metals, is not threatened with shortage of ore.

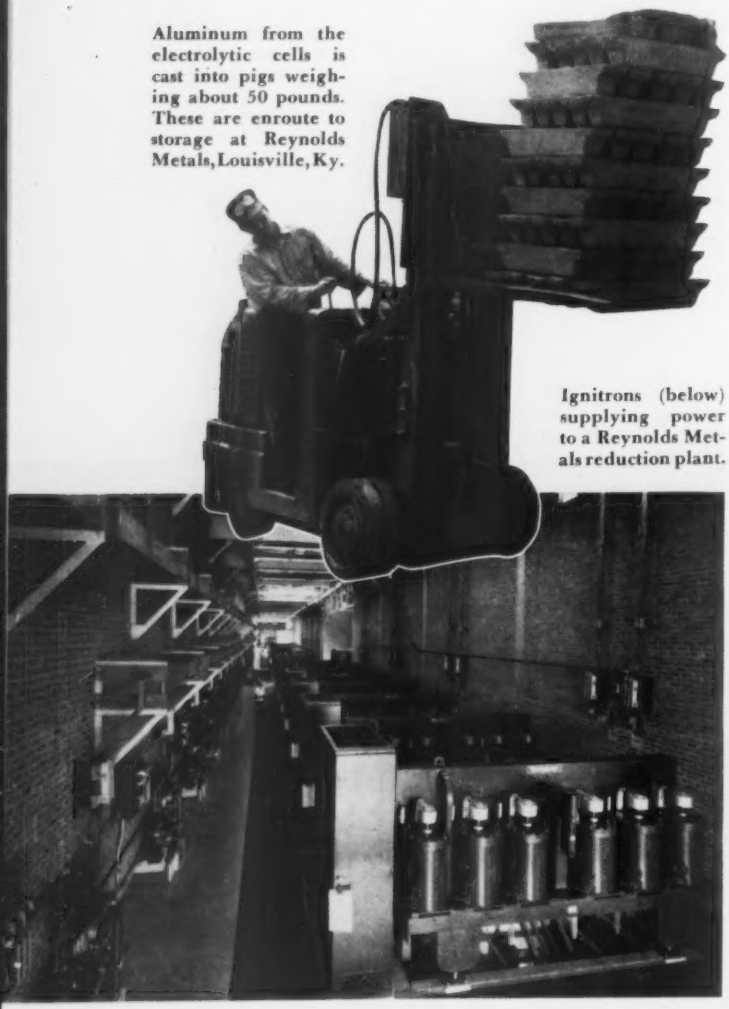
The Price of Aluminum

The aluminum industry points with justifiable pride to the price history of its product. It sells for 20.5 cents per ingot pound of 99+ percent aluminum, which compares with 20 cents in 1939 and 24.3 cents in 1929. Since War II, and until last summer, aluminum sold for less than before War II, which singularity the industry likes to point out. Most common metals have increased in price significantly since War II. Compared with their 1939 averages, the prices for most common metals at the end of 1952 had increased percentagewise as follows: copper, 118; lead, 192; zinc, 144; and pig iron, 158.

Furthermore, price per pound does not tell the whole story of aluminum, because the use may be determined by factors other than weight. Aluminum weighs about one third as much as an equal volume of steel so that a pound of it goes further for some applications, as for roofing and siding for buildings.

The electrical conductivity of electrical-conductor grade aluminum is 61 percent (IACS) minimum as compared with commercial hard-drawn copper (97 percent IACS) on a cross-section basis, but an aluminum conductor of the same conductance and length as copper weighs only 48 percent as much and is, of course, 59 percent larger in sectional area. This, however, is not quite the whole story. Because of the larger radiating surface associated with the larger cross-

Aluminum from the electrolytic cells is cast into pigs weighing about 50 pounds. These are enroute to storage at Reynolds Metals, Louisville, Ky.



Ignitrons (below) supplying power to a Reynolds Metals reduction plant.

Rolling slab prior to entering continuous mill of an Alcoa plant.

section of aluminum, the area ratio of aluminum to copper is less than the ratio of the resistances (1.59) for the same temperature rise. This ratio of cross-section area of aluminum to copper wire is only 1.36. Based on raw material costs (aluminum, 19.5 cents per pig pound; copper, 28.25 cents per pound—former OPS formula for pricing), 28.5 cents worth of aluminum does the work electrically, on the basis of equal temperature rise, of $1.00 worth of copper.

What Aluminum Can Do

Aluminum has already acquired some 4000 established and standardized end uses. The use aspect of the aluminum picture can best be viewed in terms of the various physical properties of aluminum.

Aluminum is best known, and probably most used, for its light weight—being about one third as heavy as an equal volume of iron, copper, or brass. One reason that it is the basis of the aircraft industry is obvious. (Another is that at sub-zero temperatures, strength and ductility of aluminum increase, which is opposite to what happens with iron and steel.) Wherever items must be transported or involve motion the light metal has a great advantage. Thus aluminum is being used for bus and truck bodies, and for railroad cars—both freight and passenger—for wheelbarrows, ladders, wheels, etc., reciprocating parts on machinery, as on looms, pistons, and other moving parts of engines.

An outstanding attribute that has brought aluminum many jobs is its easy workability. It can be as easily forged, drawn, rolled, and otherwise altered in shape as are most metals, and frequently somewhat easier. Of particular moment is the fact that aluminum can be readily extruded into complex cross sections. This fact is being used to advantage in the aircraft and architectural industries. By impact extrusion, tubes and cans with length-to-diameter ratios up to 16 to 1 and tolerances of ± 0.005 inch are obtainable. Aluminum can be easily drawn or spun from flat blanks into large circular shapes.

The metal can be rolled to foils as thin as 0.00025 inch. Aluminum foil has already acquired a multitude of uses—cigarette wrappers; packaging of foods and drugs; and a wide variety of household uses. Foil has many industrial purposes, of which an extremely important one electrically is as the metallic layer in capacitors and condenser bushings.

Aluminum can be given a variety of surface finishes, as obtained by grinding, polishing, buffing, scratch brushing, tumbling, sandblasting, embossing, highlighting, hammering, and fluting. Other finishes can be provided by chemical and electrolytic treatments and various combinations thereof. By anodizing, aluminum can be given a thin, hard coating of oxide that provides a serviceable finish, which has good light reflectivity when made under proper conditions. Or the anodized surface can be impregnated with dyes and certain inorganic pigments. Satisfactory methods are available for printing designs in multiple colors on aluminum sheet or foil.

Aluminum can also be electroplated with nickel, chromium, brass, copper, tin, cadmium, silver, gold, and other metals. A wide variety of paints, enamels, lacquers, and varnishes can also be utilized including luminous paints, crackle finishes; and silk-screen designs can also be applied. Vitreous enamels have also been developed for aluminum.

Aluminum is resistant to attack by many chemicals. It is substantially unaffected by acetate solvents, acetone, alcohol, ammonia, benzine, concentrated nitric acid, hydrogen-peroxide solutions, sulfur, numerous organic acids and their anhydrides, fruit acids, and many oils. It is non-toxic. The oxide is colorless, hard, and self-protecting. These qualities, combined with light weight, strength, and good appearance, are behind the present boom in aluminum siding, roofing, window frames and trim, gutters, downspouts, etc.

This 30-story building in Pittsburgh serves both as Alcoa's headquarters and as a dramatic example of aluminum's possibilities.

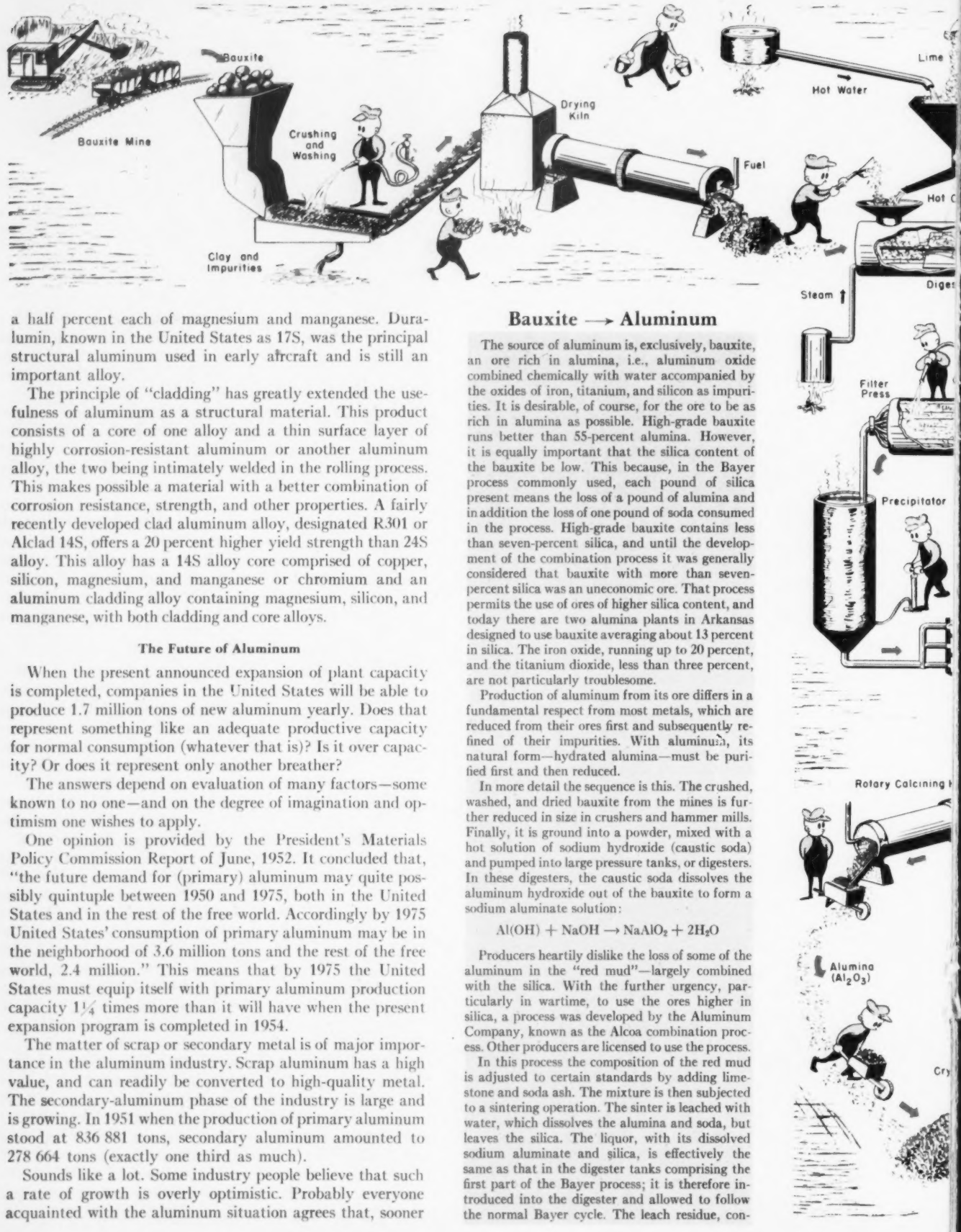
Aluminum is a good reflector of light and radiant heat. And this high reflectivity for radiant heat is well maintained outdoors. It is this quality that makes aluminum roofs so effective in reducing under-roof temperatures. This characteristic also makes it good for reflectors for portable heaters and the like. This high reflectivity for thermal radiation also makes aluminum a logical insulating material. Aluminum-foil insulation finds wide use for this purpose.

A corollary of high reflectivity for infrared radiation is low emissivity—heat-radiating power. Thus aluminum makes superior air ducts for heating systems. By comparison with a perfect black-body radiator, the radiation loss from an aluminum surface averages only 4–5 percent. This compares with 23–28 percent loss from galvanized steel and 80–85 percent loss from black sheet steel.

Aluminum is an excellent conductor of heat. This, with appearance, light weight, and resistance to attack, was responsible for its first major and still important use—kitchen utensils. This same property is used to advantage in fire-resisting laminated plastic; the aluminum is applied as a thin, heat-conducting layer under the top plastic surface.

Commercially pure annealed aluminum has comparatively low strength—13 000 pounds per square inch. However, it can be given increased strength by cold working, and by alloying. Some alloys can be heat treated with resulting substantial increases in strength. Some alloys (75S) have tensiles above 80 000 pounds.

The alloying of aluminum is a large subject in itself. The number of commercial alloys, both cast and wrought, runs to the dozens. A few outstanding ones suggest the possibilities. The earliest major one was Alcoa 3S, a non heat-treatable wrought alloy still in common use. The first heat-treatable alloy, called Duralumin, was discovered in Germany about 1910. It contains four to five percent copper and about



a half percent each of magnesium and manganese. Duralumin, known in the United States as 17S, was the principal structural aluminum used in early aircraft and is still an important alloy.

The principle of "cladding" has greatly extended the usefulness of aluminum as a structural material. This product consists of a core of one alloy and a thin surface layer of highly corrosion-resistant aluminum or another aluminum alloy, the two being intimately welded in the rolling process. This makes possible a material with a better combination of corrosion resistance, strength, and other properties. A fairly recently developed clad aluminum alloy, designated R301 or Alclad 14S, offers a 20 percent higher yield strength than 24S alloy. This alloy has a 14S alloy core comprised of copper, silicon, magnesium, and manganese or chromium and an aluminum cladding alloy containing magnesium, silicon, and manganese, with both cladding and core alloys.

The Future of Aluminum

When the present announced expansion of plant capacity is completed, companies in the United States will be able to produce 1.7 million tons of new aluminum yearly. Does that represent something like an adequate productive capacity for normal consumption (whatever that is)? Is it over capacity? Or does it represent only another breather?

The answers depend on evaluation of many factors—some known to no one—and on the degree of imagination and optimism one wishes to apply.

One opinion is provided by the President's Materials Policy Commission Report of June, 1952. It concluded that, "the future demand for (primary) aluminum may quite possibly quintuple between 1950 and 1975, both in the United States and in the rest of the free world. Accordingly by 1975 United States' consumption of primary aluminum may be in the neighborhood of 3.6 million tons and the rest of the free world, 2.4 million." This means that by 1975 the United States must equip itself with primary aluminum production capacity 1¼ times more than it will have when the present expansion program is completed in 1954.

The matter of scrap or secondary metal is of major importance in the aluminum industry. Scrap aluminum has a high value, and can readily be converted to high-quality metal. The secondary-aluminum phase of the industry is large and is growing. In 1951 when the production of primary aluminum stood at 836 881 tons, secondary aluminum amounted to 278 664 tons (exactly one third as much).

Sounds like a lot. Some industry people believe that such a rate of growth is overly optimistic. Probably everyone acquainted with the aluminum situation agrees that, sooner

Bauxite → Aluminum

The source of aluminum is, exclusively, bauxite, an ore rich in alumina, i.e., aluminum oxide combined chemically with water accompanied by the oxides of iron, titanium, and silicon as impurities. It is desirable, of course, for the ore to be as rich in alumina as possible. High-grade bauxite runs better than 55-percent alumina. However, it is equally important that the silica content of the bauxite be low. This because, in the Bayer process commonly used, each pound of silica present means the loss of a pound of alumina and in addition the loss of one pound of soda consumed in the process. High-grade bauxite contains less than seven-percent silica, and until the development of the combination process it was generally considered that bauxite with more than seven-percent silica was an uneconomic ore. That process permits the use of ores of higher silica content, and today there are two alumina plants in Arkansas designed to use bauxite averaging about 13 percent in silica. The iron oxide, running up to 20 percent, and the titanium dioxide, less than three percent, are not particularly troublesome.

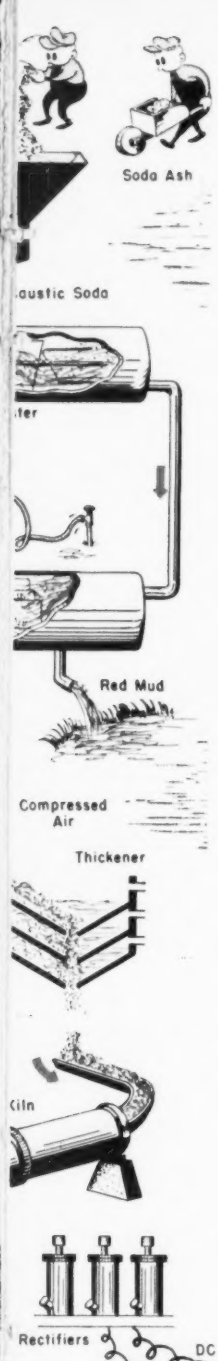
Production of aluminum from its ore differs in a fundamental respect from most metals, which are reduced from their ores first and subsequently refined of their impurities. With aluminum, its natural form—hydrated alumina—must be purified first and then reduced.

In more detail the sequence is this. The crushed, washed, and dried bauxite from the mines is further reduced in size in crushers and hammer mills. Finally, it is ground into a powder, mixed with a hot solution of sodium hydroxide (caustic soda) and pumped into large pressure tanks, or digesters. In these digesters, the caustic soda dissolves the aluminum hydroxide out of the bauxite to form a sodium aluminate solution:

$$Al(OH) + NaOH \rightarrow NaAlO_2 + 2H_2O$$

Producers heartily dislike the loss of some of the aluminum in the "red mud"—largely combined with the silica. With the further urgency, particularly in wartime, to use the ores higher in silica, a process was developed by the Aluminum Company, known as the Alcoa combination process. Other producers are licensed to use the process.

In this process the composition of the red mud is adjusted to certain standards by adding limestone and soda ash. The mixture is then subjected to a sintering operation. The sinter is leached with water, which dissolves the alumina and soda, but leaves the silica. The liquor, with its dissolved sodium aluminate and silica, is effectively the same as that in the digester tanks comprising the first part of the Bayer process; it is therefore introduced into the digester and allowed to follow the normal Bayer cycle. The leach residue, con-



taining most of the silica and negligible amounts of alumina, is discarded as "brown mud." By this route four to six pounds of bauxite have been converted to two pounds of alumina, which, in turn, with ten kilowatthours of electricity and 0.6 pound of carbon, becomes one pound of aluminum.

The impurities in the ore, not affected by the caustic, remain in solid form and are removed from the sodium aluminate solution when it is pumped from the digesters into filter presses. The solution, being liquid, passes through the filters, while the impurities remain behind as a residue. This residue is commonly called "red mud."

After passing through the filter presses, the sodium aluminate solution is pumped into precipitating tanks as high as a five- or six-story building. As the solution slowly cools in these tanks, fine crystals of aluminum hydroxide are added as "seed" and aluminum hydroxide precipitates from the solution.

$$NaAlO_2 + 2H_2O \rightarrow Al(OH)_3 + NaOH$$

The aluminum hydroxide is next separated from the solution and washed to remove the last traces of caustic. The caustic-soda solution is then pumped back into the digesters to treat a new batch of bauxite; while the aluminum hydroxide, which is nothing more than aluminum oxide chemically combined with water, is heated white hot in large rotating kilns to drive off the chemically combined water and change the character of the material so it will not reabsorb moisture from the air:

$$2Al(OH)_3 + \text{heat} = Al_2O_3 + 3H_2O$$

The Hall-invented technique continues the process where the Bayer method leaves off—with alumina. The electrolytic cells, in which the alumina is reduced to aluminum in the metal-producing works, are rectangular in shape and comprise steel shells lined with carbon. The reduced aluminum rests on the carbon bottom of the cells and serves as the cathode. The current is led into each cell through carbon anodes suspended from above the cells on overhead busbars. The capacity of most cells used by the industry ranges from 500 to 1500 pounds of aluminum a day.

The successful operation of the Hall process is based on the fact that alumina when dissolved in molten cryolite can be decomposed by the passage of an electric current without attack of the cryolite.

In the operation of an electrolytic cell, the cryolite bath material with added alumina is introduced into the cell. After it is fused by the electric current, the current passing through the bath separates the dissolved alumina into its component parts of aluminum and oxygen. The oxygen liberated at the anodes combines with carbon and escapes as carbon-dioxide gas through the frozen surface crust of the bath. The aluminum is deposited on the bottom of the cell where it remains as a molten layer. It is tapped from the cell into large ladles and cast into pigs of 50 to 1000 pounds. The process is continuous.

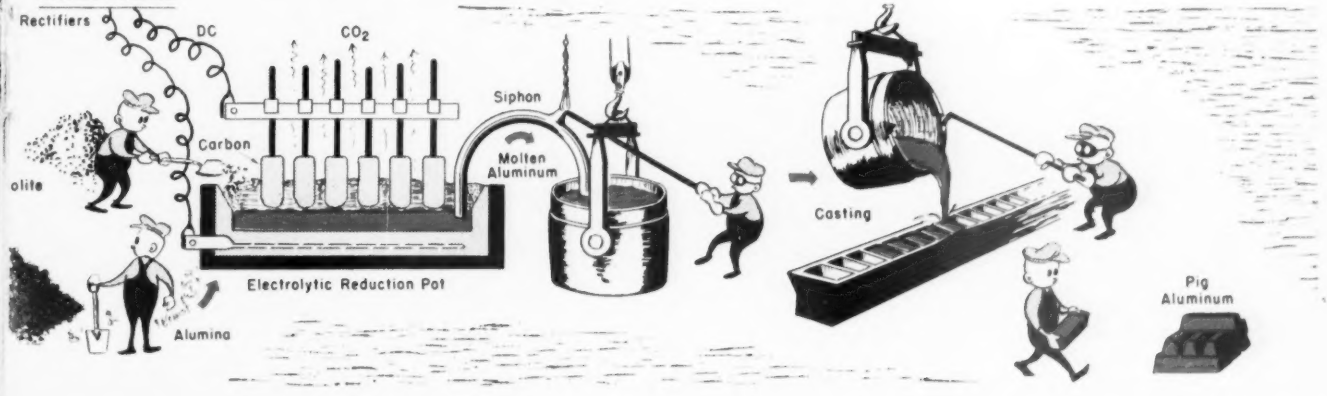
or later, the industry will grow to that size. Some think well beyond it—and before 1975.

Any marked falling off in aluminum requirements for military applications could mean that, with all these shiny new plants ready to do business, we would, as was incorrectly predicted for the period following World War II, have aluminum "coming out of our ears." Also, although there are several extremely attractive potential new uses for aluminum on the horizon, they will not develop overnight.

Take "tin" cans for example. It is quite possible that aluminum will some day replace some, if not a major part, of the packaging presently done with tin-coated steel. (About 3.8 million tons of steel are annually used for tin plate in the United States.) Sizable test runs show aluminum to be satisfactory for many canning functions—food included. And there are many potential advantages. The cans are lighter—hence shipping costs are less. It would ease the tin situation, which might again become critical. The directly printed aluminum can has excellent appearance appeal. While the aluminum can is not now competitive in cost with the tinned can, the spread will decline and perhaps disappear. Aluminum cans will likely appear first for such purposes as engine oil, bar-dispensed canned beer, and the large food containers used by hotels and restaurants. In such cases the scrap value of the container becomes important. Salvage of aluminum cans is much more feasible than for tinned cans. However, before aluminum sweeps the metal-container field, can-making machinery will have to be altered—at considerable expense, and the consuming and industrial public educated to this change. All this will take time.

The industry points out how the use of aluminum in automobiles has risen steadily to a present 20 pounds per passenger car. Much more could be used, up to virtually the whole car in fact. (Europe has aluminum-body passenger cars, but there, weight economy, in view of European fuel costs, makes aluminum more nearly competitive with steel in cost.) But, assume the amount of aluminum per car were only to double. The automobile industry would, with a six-million-car year, require an additional 60 000 tons of aluminum. If the amount of aluminum per automobile should go to 500 pounds—and that is no strain on the imagination—the tonnage required would be nearly equal to the entire expanded productive capacity of the United States (not counting scrap).

Aluminum is not without competitors: plastics, magnesium, stainless steel, and, the newcomer, titanium. However, in looking at aluminum from all angles—adequacy of sources, costs of production, and qualities—one cannot but arrive at the conclusion that the metal has a fast-growing future with no absolute ceiling in sight.



Perhaps no subject has been more discussed in the electrical industry than that of aluminum versus copper. But aluminum applications are, in many cases, no longer in the discussion stage. Many valuable uses have been found for the metal.

Aluminum in the Electrical Industry

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The much-discussed shortage of copper and a trend toward favorable economics by using aluminum as a replacement have caused the lighter metal to be considered for virtually every present electrical application of copper or copper-base alloys. By no means were all of these considerations recently conceived; aluminum had previously been applied to electrical equipment for many of the applications now being publicized. The light weight, good appearance, and nonmagnetic properties of aluminum are well known and were put to good use for current-carrying applications long before the copper shortage developed.

The technical problems involved in the use of aluminum for some purposes have been considerable. Until recently, therefore, incentive to solve these problems was small. Now that the incentive is more substantial, the problems are being solved as rapidly as possible to conserve copper for uses where it is definitely required, and to take advantage of the potential savings.

Joining Problems

Along with its potentialities, aluminum has certain limitations that must be considered when applying it to electrical equipment. Of paramount importance in making the transition to aluminum conductors are the joints, either between aluminum and aluminum or, in some instances, aluminum and copper. The rapidity with which aluminum forms an electrically insulating oxide layer and its rapid corrosion when in contact with copper under humid conditions are well known. These characteristics make it necessary to thoroughly explore the contemplated joints on every design; the joint must not only have low electrical resistance initially, but also must retain this excellent conductivity under all its anticipated environments.

To minimize the formation of aluminum oxide or corrosion products, the general practice has been to protect the joint surfaces with special greases, after which the metal surface is abraded (through the grease) by a wire brush. This removes the aluminum oxide, and the grease retards its reforming. Frequently the greases contain metallic powders, which help break down any high-resistance film as the joint surfaces are pressed together. Quite often these greases are incorporated into the crimp-type connectors used frequently for joining aluminum wire or cable.

Laboratory tests show that joint-protective compounds must be used with caution. Some of them actually cause the joint resistance of aluminum-to-aluminum bars to increase more rapidly under certain conditions than if the bars were left uncoated and merely cleaned by abrasion before joining.

Tests and field experience clearly show the effectiveness of silver-plated aluminum-to-aluminum and aluminum-to-copper joints. When the joint surfaces are silver plated, special compounds may not be necessary and the connection is the same as that of silver-plated copper. Because aluminum is more difficult to plate than silver, extra processing operations are necessary (see Table I, p. 101).

The coefficient of expansion of aluminum is 1½ times that of copper. Electrical-conductor-grade aluminum with approximately 10 percent cold work, and at 125 degrees C and 7000-pound load, has a creep rate some 100 times greater than copper under the same conditions. These two characteristics complicate bolting procedures. Experiments to produce better bolting techniques have been made. The effectiveness of using Belleville spring-type washers (see diagram on page 101), larger flat washers, or, in some instances, aluminum bolts to match the expansion of the bars, has been demonstrated on joints exposed to severe thermal cycling.

Well known is the ease with which copper can be joined to itself without hazardous fluxes by soldering, brazing, or even burning the ends of twisted strands together. Although techniques are available for soldering or brazing aluminum, the known fluxes have sufficient shortcomings to preclude

their use around insulation or stranded wires in most applications. Where the part can be first tinned with a strong flux that can be thoroughly removed before insulation is added, the conventional noncorrosive resin flux can be used for final soldering.

The use of ultrasonics to tin aluminum without the use of a flux is being investigated. Small soldering baths that oscillate the solder by magnetic transducers vibrating at 20 000 cycles per second have shown the feasibility of tinning aluminum by this method. Development is under way to create equipment suitable for handling volume-production requirements.

Copper is conveniently brazed with self-fluxing Phos-Copper alloy. For aluminum there is no counterpart. All fluxes tested to date are sufficiently objectionable to prevent their use for joining insulated aluminum conductors. Fortunately, aluminum can be joined to itself without a flux by inert-arc welding procedures. The equipment is somewhat expensive and the operators need training, however on many applications the technique can be economically applied.

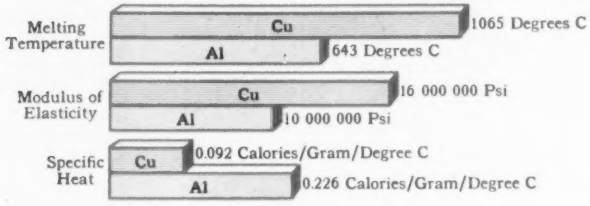


Fig. 1—The relative values of three important characteristics of aluminum and copper.

Mechanical Aspects

In addition to the metal-joining problem, some of the mechanical properties of aluminum create additional design complications. Even when allowance has been made for increased area to obtain conductivity comparable to copper, conductor-grade aluminum is not mechanically as strong. Thus where conductors are subjected to structural loads or applied forces, allowance must be made for the lower strength. On aluminum busbars this has, in some instances, been compensated for by adding the additional metal in the direction where loading is most severe.

Frequently an effort is made to increase the strength of aluminum by severely cold-working the metal. When this is done the ductility may be reduced to the point where some difficulty is experienced in making bends that had previously been made successfully with hard-drawn copper.

The ease with which aluminum anneals and its lower strength at elevated temperatures introduce certain problems. For example, when wire is enameled it may go through baking towers that operate at temperatures as high as 400 degrees C. Thus the tension must be carefully controlled so that the wire is not stretched and its cross section reduced. The insulated wire is now annealed (even though it was hard when it went into the baking towers). The ease of stretching of the soft aluminum in relation to copper presents a substantial problem with winding machines such as used to wind armatures.

Not to be ignored in design calculations is the lower modulus of elasticity of aluminum, which is only two thirds that of copper. Thus, within the elastic range, for the same mechanical loadings, aluminum elongates about 1½ times copper of the same cross section. Sufficient consideration, therefore, must be given where permissible deflection is small.

TABLE I—THERMAL AND ELECTRICAL PROPERTIES OF SOME ALUMINUM ALLOYS

Material	Alloying Elements	Thermal Conductivity*—CGS Units	Electrical Conductivity†—Percent
Copper Wrought		0.94	100
Aluminum Wrought			
EC	99.45% minimum Al	0.56	62
2S	99% minimum Al	0.52	57
63S-T6	0.4% Si; 0.7% Mg	0.50	55
17S-T4	4% Cu; 0.5% Mn; 0.5% Mg	0.29	30
75S-T6	1.6% Cu; 2.5% Mg; 0.3% Cr; 5.6% Zn	0.29	30
Aluminum Cast			
13	12% Si	0.29	31
43	5% Si	0.39	42
195-T4	4.5% Cu; 0.8% Si	0.33	35
355-T6	1.3% Cu; 5% Si; 0.6% Mg	0.34	36

*At 25 degrees C (77 degrees F). Units are Cal/sec/cm²/cm/deg C.
†At 20 degrees C (68 degrees F), for equal cross section and length of copper and aluminum.

Typical Applications

Because the electrical industry has recognized that significant differences exist between aluminum and copper, numerous laboratory tests and experimental models had to be completed before the use of aluminum could be safely extended. In many instances, this work has been finished and aluminum will be more broadly applied.

Busbar

As an example of possible applications, consider busbar, a high-tonnage item. Busbar is used in many different sizes,

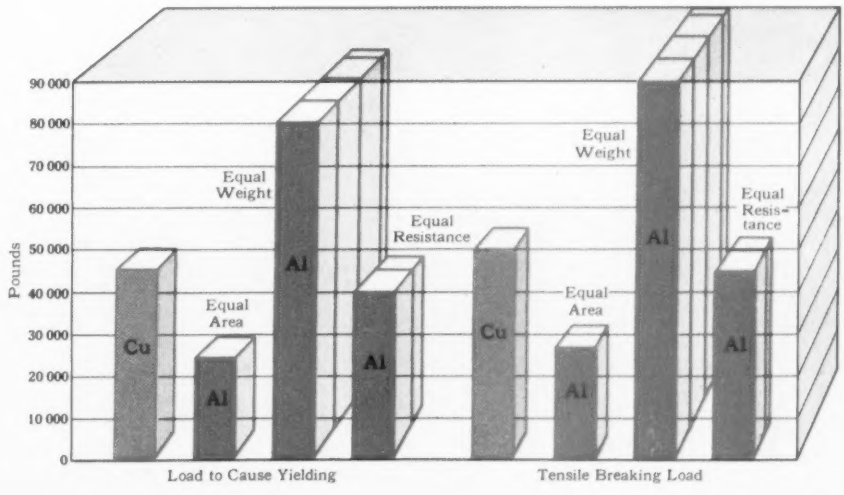
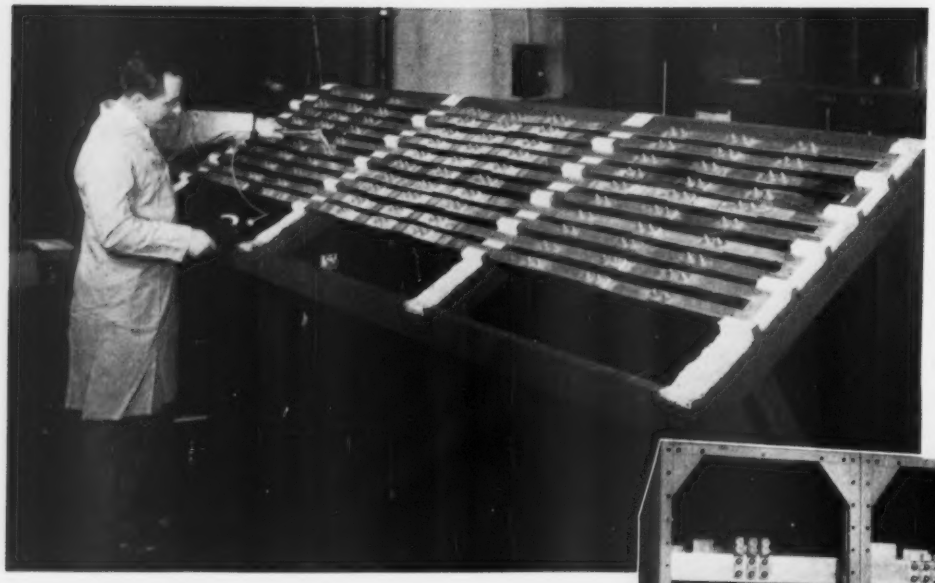
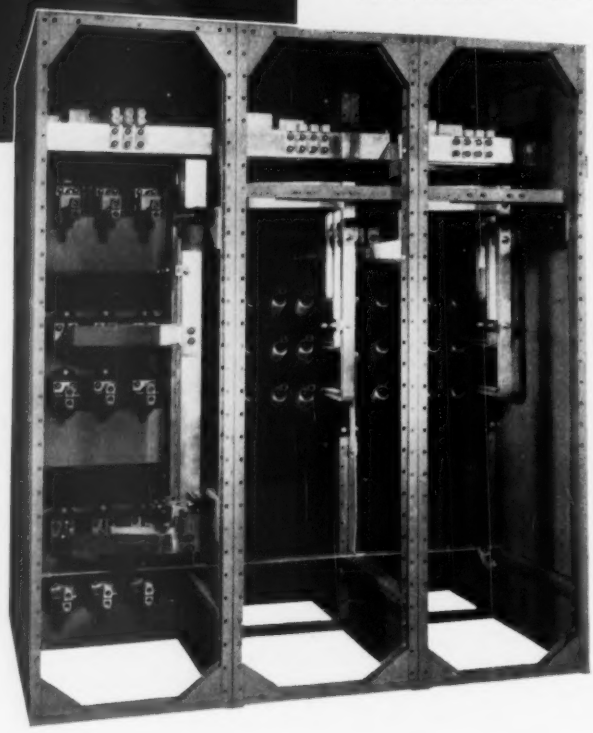


Fig. 2—A comparison of some copper and aluminum properties; at left the load to cause yielding, and at right the tensile breaking load. The comparison in each of these graphs is between hard copper (one square inch in cross section) and hard aluminum of equal area, weight, or resistance.



A test arrangement for evaluating aluminum joints. Both the temperature rise and the joint resistance were measured in this test.



One of the first low-voltage, metal-enclosed switchgear with aluminum busbar.

varying from small rectangular strap for resistance-welder control panels to the large bus sections used on switchgear equipment or for bus duct. Actually, use of aluminum busbar dates as far back as 1895, when it was used at Niagara Falls. Aluminum busbar has also been used for pot lines in the aluminum industry for quite a few years. Westinghouse used aluminum busbar in 1936 on switchgear equipment for a series of Navy destroyers where light weight was desirable. As far as is known, this application, which used Belleville-type spring washers, proved satisfactory.

To make the use of aluminum for busbar commercially feasible, several factors had to be studied. The best surface preparations were determined to assure good electrical conductivity of joints under various atmospheric and temperature conditions; plating techniques were developed for aluminum (see Table II); the type of bolting and pressures necessary to maintain a good electrical joint were established; and the current-carrying capacity of aluminum bus conductors was determined under various conditions of spacing and arrangement. Also, the aluminum fabricating industry had to determine how to economically process aluminum busbar to the close requirements of surface finish and tolerances required by the electrical industry.

Although the difference in electrical conductivity of aluminum and copper is well known, the values can by no means be used to calculate the most efficient section size of aluminum to be used to replace copper. The increased surface area of aluminum means greater heat dissipation, and in most cases the current-carrying capacity of a busbar is dependent upon its temperature rise.

Aluminum busbar has been used satisfactorily in control apparatus for resistance-welding equipment and in network protectors for several years. It is now being used in certain low-voltage metal-enclosed switchgear, and this application will consume substantial quantities of aluminum. Experimental aluminum-bar bus duct has been built, and in the future aluminum bars will probably be used in quantity.

Rotating Equipment

Although aluminum has been used in windings for motors and generators, the size of the equipment in most instances has to be increased. In a few instances aluminum wire can be applied to starting windings of motors with no increase in size of stator. Although experimental small motors have been produced by Westinghouse, problems of connections and wire handling, in addition to the increased size, make aluminum windings unattractive at present.

The increased use of aluminum die-cast rotors to replace copper windings in small induction motors has conserved a considerable tonnage of copper in this field, and this application is expected to continue.

Westinghouse has manufactured a number of motors ranging from 1½ to 10 hp utilizing aluminum wire; these motors are now in service and will be closely followed for evaluation. They will provide experience with aluminum wire in case (1) the copper supply is drastically limited in the future, or (2) the cost differential between aluminum and copper wire becomes more favorable toward aluminum.

During the pursuit of designs to create larger rotating electrical machines, consideration was given to the use of

aluminum in rotor windings. The development of inner-cooled windings of copper for turbine generators resulted in a tool that proved more efficient and economical than would have been possible by using aluminum. Therefore, present plans call for copper for rotor and stator windings in large turbine generators. The amount of copper per equivalent rating of machine has been materially decreased through the development of inner-cooled windings.

Transformer Windings

Lightweight coils of rectangular aluminum wire, inert-arc welding apparatus, and crimp-type terminals containing a joint-protective compound were introduced in the manufacture of certain Westinghouse transformers last year. Actually 20 aluminum-wound dry-type transformers (ranging from 3 to 25 kva) were built in 1948; a destructive test performed on two of these transformers indicated that neither the operation nor the joints were noticeably affected after 3½ years of field operation.

For about a year, limited numbers of ASL dry-type transformers have been produced with aluminum conductors. The electrical characteristics of aluminum- and copper-wound transformers are identical, but the overall weight of the aluminum version is from two to five percent less.

Aluminum appears to have more justification in dry-type than in oil-filled transformers. The dry-type transformer has relatively large insulation clearances, and the increase in conductor size has less effect on the overall size. To maintain anywhere near the same size of oil-filled transformers and utilize aluminum, a totally different type of insulation would be required; this is because the oil-filled transformer is dependent upon the close spacing and high dielectric strength of the insulation. Although of minor importance, aluminum is better than copper as regards its catalytic effect upon insulating oil.

Aluminum coils for dry-type transformers present no particular manufacturing difficulties. Joints in windings, leads, and busbars are either welded, bolted, or joined by a crimp-type conductor. Welded joints are arc welded under inert gas. Bolted joints are silver plated, and the bolts used are of cadmium-plated steel.

Current-limiting reactors, too, are using aluminum—and with considerable benefit. The saving in copper alone will amount to about 200 tons a year for Westinghouse. An aluminum-wound reactor weighs about one fourth less than a comparable one of copper.

The rapid oxidation of aluminum in air—at times a problem to engineers—is in this case an advantage. The oxide produced is a fair insulator. Thus in aluminum-wound reactors it is not necessary to apply insulation between individual strands to cut down eddy current losses. To reduce this loss in copper reactors, alternate layers of strands have been enameled. The lower strength of aluminum has, however, required more supporting columns and bracing.

Lamp Bases

By now, aluminum bases for incandescent light bulbs are becoming more and more familiar to our everyday life. Before this increasing use of aluminum bases took place, however, there were many problems to be solved. For example, the grade of aluminum that would stand the fabricating operations had to be found. The decreased tool life involved with aluminum (versus brass) for these applications made it necessary to redesign tooling. Although a bright-dip solution for aluminum has been available for some time, this process is far from being as efficient in cost and operation as a bright dip for the brass bases. Since the appearance of such a commodity is important, a great amount of time and effort was spent in obtaining a finishing process that would give the desired finish at a reasonable cost.

The much-discussed poor solderability of aluminum was

TABLE II—BUSBAR PREPARATION

Treatment	Steps	
	Aluminum	Copper
Vapor degrease	1	1
Bright dip		2
Alkaline etch	2	
Rinse	3	3
Nitric acid bath	4	
Rinse	5	
Sodium zincate	6	
Rinse	7	
Silver strike	8	4
Silver plate	9	5
Rinse	10	6
Dry	11	7

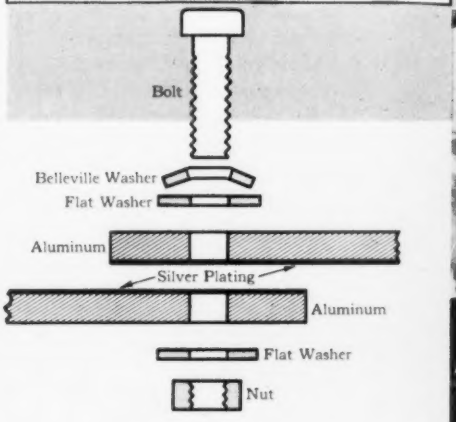


Fig. 3—A simplified, exploded view of an aluminum-to-aluminum joint using Belleville washers to apply compression. Inner surfaces of the aluminum are silver plated.

A top view of a current-limiting reactor with aluminum windings.

even more important for this application than others since the production rate and cost values for operations on lamp bulbs are determined in fractions of a cent. Any additional time required to obtain a good joint had to be minimized to keep the cost within a reasonable range.

Electrolytic corrosion was another major factor to be considered and numerous controlled humidity and environmental tests were made to assure the industry that aluminum-base bulbs would stand up when used in brass sockets for indoor applications. These tests obviously had to be followed by extensive field tests, and it is still questionable whether or not an aluminum-base lamp will prove satisfactory for outdoor applications, especially near the seacoast, regardless of whether the socket is made of aluminum or brass. On the other hand, aluminum bases should prove extremely satisfactory for the majority of applications and conserve our national copper supply for other uses. Work is being conducted in an attempt to develop a coating or finish that will make it possible to use an aluminum-base lamp bulb in all normal environmental conditions, indoors or out.

Another major problem with lamp bases is the low melting point of aluminum. This gave considerable trouble in attaching the glass to the base. Fairly elaborate inspection means are necessary, therefore, to assure that no melting or flowing of the aluminum occurs at the bottom of the base. Although the problems appear immense in the use of aluminum lamp bases, a good percentage of them have been solved and the cost has been maintained at a low level.

Miscellaneous Applications

Solid-conductor aluminum wire for electric-range wiring has been under test for well over a year. Joints tested under varying conditions of humidity, temperature, and current cycling, pressure, surface preparation, and material combinations indicate that aluminum wire performs as satisfactorily as copper wire. Correct pressure applied to the joint during the original assembly is the important factor. Since applying the correct pressure on a screw depends on the assembler, design engineers are working toward simplified terminations to eliminate the human variation. Here there are no space requirements to hinder the change to aluminum wire.

Large impact-extruded cans for outdoor capacitors and cooling vent fingers for generators are some of the newer nonconductor applications for aluminum. In the case of the outdoor capacitor can, a cylinder approximately 9½ inches in diameter by 16 inches high was needed to encase a lightweight compact capacitor; many metals and means of fabrication were considered. The impact extrusion of aluminum won out both from the standpoint of cost and performance. The cooling vent fingers are nonmagnetic structural shapes (straps approximately 3/32 by ½ by 6 inches) used to separate electrical sheet-steel laminations and facilitate cooling. Brass was previously used for its nonmagnetic properties and good formability, but now aluminum can be used at less cost and a savings of approximately 250 000 pounds of brass per year, which in turn means a saving of approximately 175 000 pounds of copper per year.

The use of aluminum castings to replace those of copper-base alloys is being investigated. An illustration is the jumper-plug casting used to house the plug connections made between subway cars. Aluminum enables both a cost and weight reduction without impairing function. Inasmuch as these plug grips are subjected to considerable mechanical abuse, numerous tests were necessary to evaluate aluminum's ability to "take it."

The Basic Problems Remaining

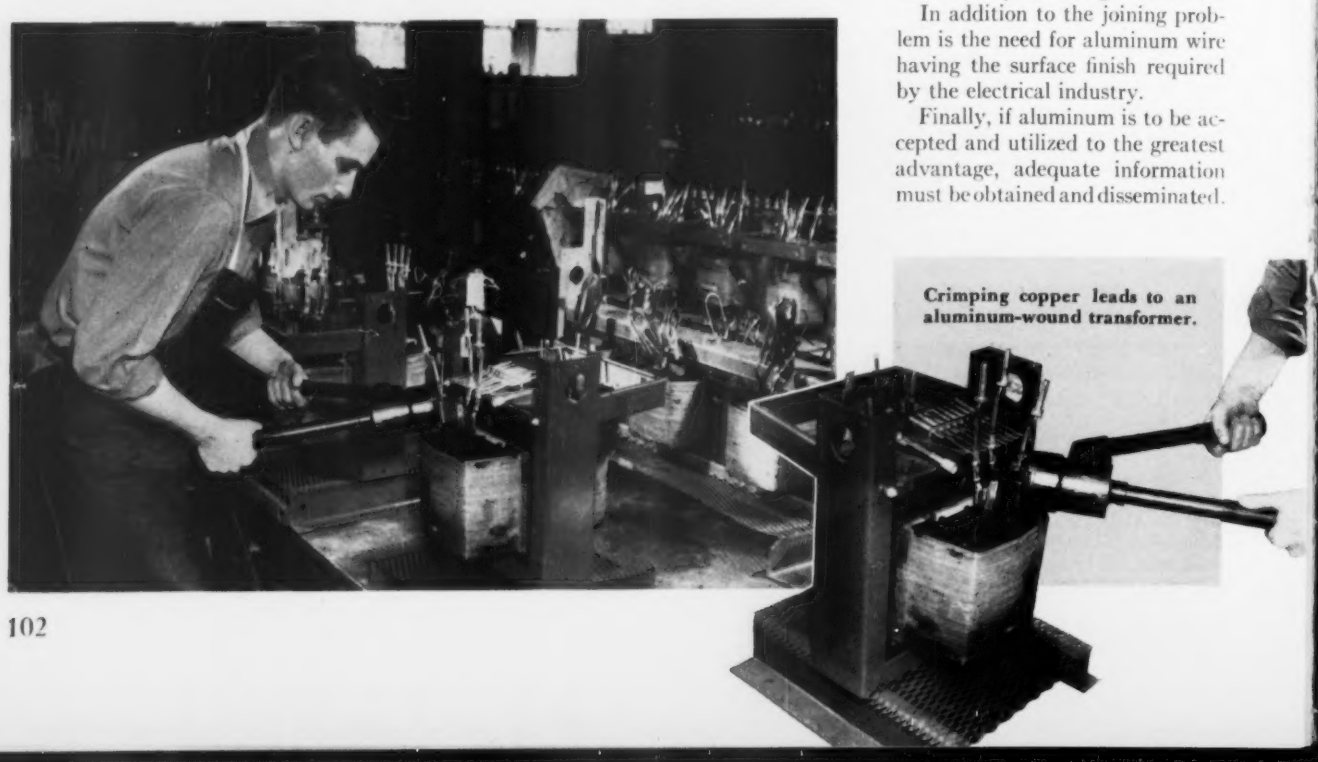
Aluminum will undoubtedly find its way into more and more applications in the electrical industry, and will thus increase in tonnage volume. However, there are still a few basic problems that, if not solved, may retard the use of aluminum.

The necessity for a soft-soldering technique that does not involve a corrosive flux or a flux detrimental to electrical insulation is of great importance in the electrical use of aluminum; the same requirements are predominant in the applications of brazing techniques. In addition to the drawback imposed on the application by the currently available brazing fluxes, there is the problem of competing with economical brazing operations such as obtained by utilizing Phos-Copper or Phos-Silver (self-fluxing) brazing materials for copper.

When mechanical terminations of the crimp type are used, less costly terminals and methods of applications will undoubtedly encourage their use.

In addition to the joining problem is the need for aluminum wire having the surface finish required by the electrical industry.

Finally, if aluminum is to be accepted and utilized to the greatest advantage, adequate information must be obtained and disseminated.



Crimping copper leads to an aluminum-wound transformer.

Physicists in Industry

The question of whether fundamental research has a place in the industrial laboratory is one that has been bandied about for many years. However, the increased tempo at which we are applying fundamental knowledge has resolved that question—the need is now self-evident. As a result, the physicist has gained a unique new stature in the industrial world.

DR. DANIEL ALPERT, *Research Laboratories, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

NOT MANY years ago, a physicist in industry was an anomalous character, a long-hair, a prima donna, and a problem child to administrative personnel in general. Today, the physicist is one of the most respected and sought-after members of the technical staff in almost every industrial activity, from the ancient fields of acoustics and optics to the most recent ones of electronics and nucleonics.

What explains the tremendous change in the position of physicists in industry, and at Westinghouse in particular? Most people in a position to know agree that a trend toward the recognition of physics in industry has been taking place for at least two decades; this trend was, of course, dramatically speeded up and publicized during World War II. The two outstanding military developments of the war, radar and the atomic bomb, were inspired, directed, and largely carried out by physicists; as a result, physics and physicists have become household words. During the development of radar in the early 1940's, most electrical engineers had little acquaintance with resonant cavities, waveguides, or radio-frequency discharges in gases. In the case of the atomic bomb, the average professional engineer had little or no training in the fundamentals of nuclear physics, and therefore did not have the necessary background for work of this type. Even the layman has come to realize that the physicist with his broad training in fundamentals is able to do certain pioneering development that the professional engineer with his more specialized training cannot.

Recognizing the significant role of physicists in industry, Westinghouse, in 1937, instituted the program of Westinghouse Research Fellowships to attract physicists and other scientists into its laboratories. In 1942, it was the physicists among the Research Fellows who developed for the Armed Forces such crucially important radar components as crystal diodes, TR switches, beacon reference cavities, pulse transformers, spectrum analyzers, as well as complete radar equipment. When key personnel were desired for work on the Manhattan Project, a number of physicists were again called upon to represent Westinghouse. As the result of these experiences, no one questions the necessity of having trained physicists to do applied physics and, on some occasions, even to do engineering.

Since the war, Westinghouse has embarked on a new type of research program instituted by Dr. J. A. Hutcheson, the Director of Research. A number of promising young physicists have come to the laboratories, not to apply their knowledge and training to practical problems directly, but to continue their search for new knowledge in the broad areas of physics, which are of great importance to the electrical industry. At present, nearly 40 percent of the total effort at the Research Laboratories is devoted to fundamental, rather than applied research.

Role of Fundamental Research in Industry

To distinguish between applied physics and fundamental physics is a rather subtle matter. In fact, it is almost impossible to tell the difference merely by looking at the instruments used or the day-to-day activities of the physicist himself. Actually, the difference lies primarily in the *aim* or *motivation* for doing the research. Applied physics has an end product in mind, and success or failure is ultimately judged by whether that end product has been achieved or improved. In pure or fundamental physics, success is measured only by whether new knowledge has been achieved, new theories have been created, or new experimental facts have been ascertained. The difference between pure and applied physics may be not in what the physicist is doing today, but in what he will do tomorrow.

In applied physics or development, a goal can be established and a program of activity accurately defined. By its very nature, however, fundamental research does not lend itself to rigidly specified direction. For example, Roentgen set out to study electrical conduction in gases and discovered x-rays instead. Becquerel started to study the relation between luminescence and x-rays, but ended up with the discovery of radioactivity. This kind of thing also happens in our laboratories. Two years ago, one group was set up in the Physics Department to study the behavior of negative ions in gases and another group to study the behavior of positive ions. Today, very significant progress has been made in both programs and in both fields. But the group that set out to study negative ions has not examined one to this date; instead they have developed some remarkable new techniques and discovered important knowledge about the formation of positive ions.

"The great testimony of history shows . . . how science, even of the most abstract and recondite kind, pays for itself again and again in providing the basis for radically new technological developments."

J. R. Oppenheimer

The only investigation of negative ions—and it has been done in a completely novel fashion—has been carried out by the group whose original goal was the study of positive ions.

Thus it is necessary in fundamental research to indicate the general fields of proposed activity rather than to formulate specific projects. The fundamental research activities in the Research Laboratories include a very broad program in physics, covering such general activities as gaseous electronics, atomic physics, solid-state and nuclear physics. The most important question in these activities is not "which product will be improved by this effort," but rather "is good physics being done?"

If the specific goals of fundamental research must be as

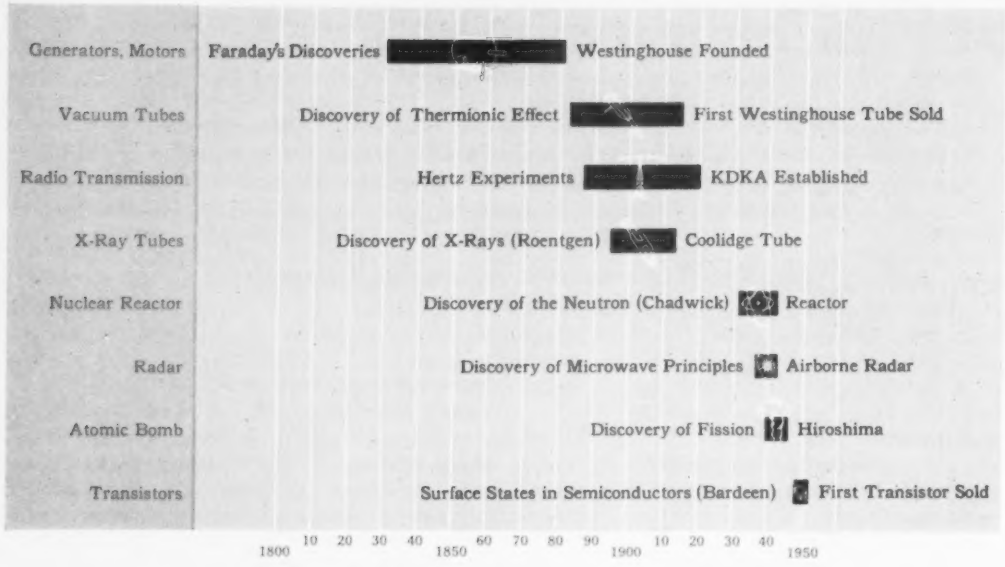


Fig. 1

The time interval between discovery of fundamental knowledge and some event that representsthe commercial application is ever shorter. The length of each bar in this graph indicates this time in years.

broadly defined as has been indicated, and if the exact remuneration cannot be determined beforehand, why do we put our eggs in the basket of fundamental research? This is not just a rhetorical question. Many engineers and almost every young staff member asks why we do fundamental research. This question is even asked by our most capable physicists, who can any day walk out of the Laboratories into positions of security and prestige at well-known universities.

To help answer this question, consider Fig. 1, which indicates the time interval between fundamental research and some of its eventual industrial applications. This graph includes products that have been of tremendous importance not merely to Westinghouse, but to civilization: generators, motors, vacuum tubes, radio, nuclear reactors, atomic bombs, and transistors.

Thus, for motors and generators, 51 years elapsed between Faraday's discovery of the laws of magnetic induction and the founding of the Westinghouse organization, one of the original manufacturers of dynamos in America. Further on the list are shown the time intervals for other products; it took from 1887 to 1920—33 years—before the wireless transmission of electromagnetic waves, discovered by Hertz, was incorporated in the first commercial broadcasting station, KDKA; 18 years between the discovery of x-rays and the production of the first Coolidge tube, and so on. As time has passed, one can see the speed-up brought about by the tremendous technical strides of industry. Note that in the postwar period the transistor proceeded from the discovery of the underlying scientific knowledge to the sale of the first transistor in a span of less than four years!

Physicists were unnecessary in industry some years ago. During the 19th and early 20th century, many years transpired between a scientific discovery and the visualization of its possible uses. George Westinghouse was not even born until 15 years after Faraday's famous discovery. As time has passed, however, the interval has progressively become shorter and shorter; we have every reason to believe that this trend will continue. But even on the present time scale *the interval is less than the time required to educate an engineer in a new field.* Can it come as a surprise, then, that while most of the important inventions in the period between 1890 and 1920 were made by engineers, all of the last five products in Fig. 1 were invented by physicists? That is, physicists were responsible not only for the discovery of the fundamental knowledge that made the devices possible, but even for the invention of the devices themselves. In most cases, the inventions were made by physicists who devoted their careers primarily to fundamental research, and in some cases while they were actually engaged in it. Thus, Bardeen and Brattain were not seeking a new electronic device when they came upon and invented the transistor; they were seeking an understanding of the surface properties of semiconducting solids.

The production of new knowledge has invariably been followed by new invention; on the present time scale, the laboratory that produces the knowledge is in the best position for acquiring the resulting patents. This introduces another important reason for doing fundamental research. Suppose some other organization comes up with the "Big Idea." Where do we stand within such an accelerated time scale? How will we get the necessary information when scientific publications often run two or three years behind the original discoveries even in the absence of company restrictions? We then must rely on a staff of scientists actively engaged in the given research field to acquire information from other sources and to be able to digest it into understandable and usable form. It can be stated categorically that when a given company has been lucky enough to come up with a "Big Idea," no competitor has made great strides toward overcoming the lead without an adequately trained staff of physicists and other scientists in that field.

The trend indicated in Fig. 1 supplies adequate reasons for undertaking fundamental research. These reasons represent benefits of a long-range nature, similar to those derived from plowing money back into an expansion program. They are less direct but no less real than cash dividends. In addition, there are reasons for doing fundamental research that are of immediate benefit to a company:

Consultation with Manufacturing Divisions—Even after a product has been manufactured for many years, there is always great need for improvement and thus for consultation with experts in various fields of physics. In new fields of industrial activity, such as atomic power, the physicist may be called upon for advice and consultation relating to long-term policy, as well as immediate engineering problems. A sizable program of fundamental research is justified even if based on these grounds alone.

Procurement and Training of Physicists for Advanced Development Groups—On the basis of the information in Fig. 1, it is not surprising that in recent years some manufacturing operations have found it necessary to have men trained as physicists to take over key roles in development or even in production. The procurement and training of such men is one of the important functions of the fundamental research program. Every year, a number of people whose talents fall into engineering or administration transfer from the Research Laboratories into advanced development and engineering staffs elsewhere in the Company.

Acquisition and Digestion of Knowledge—We have already mentioned the importance of the acquisition and synthesis of knowledge with regard to acquiring information in a new field. It is also often necessary to write up-to-date text books in old fields of physics. Quite apart from new discovery, fundamental research provides the means for learning and analyzing existing knowledge.

Maintenance of High Scientific Standards and Methods—Though the practical methods of production are often based on working hypotheses and trial and error, there is a basic desire to understand the fundamental processes; sometimes such an understanding provides the only means to a practical solution. The standards and ideals set up by scientists in fundamental research serve as a means for attaining higher standards in our entire technical staff.

To summarize briefly, the time gap between the discovery and the commercial utilization of knowledge is ever narrowing. So rapidly is industry using up available information that it must invest some of its capital toward pushing the frontiers of knowledge forward, not as an altruistic gesture toward society, but as a planned investment for its own financial well-being. The tremendous diversification of the products of a company like Westinghouse practically insures the value of fundamental research in very broad areas of physics.

Building a Scientific Tradition in Industry

What if industry decides to initiate a far-sighted program of fundamental research? Does this decision alone guarantee the formation of a strong program of fundamental science within a few years? The answer is: It is no more possible to purchase a tradition of science than it is to purchase a tradition of pennant-winning baseball teams. In addition, research has a number of problems that baseball teams do not. For example, it may come as a surprise to people in industry, but it is nevertheless true, that the truly outstanding young graduate student in physics is usually encouraged by his professors to continue in fundamental research and often discouraged from considering a career in industry. The common belief among research physicists, justified by decades of history, is that fundamental or pure physics is carried out only in academic laboratories, and that the industrial laboratories are interested only in applied physics. Thus the administrator of a fundamental research activity in industry not only has the task of selling physics to industry, but also the even more difficult task of selling industrial research to physicists.

*"Once basic knowledge is acquired, any attempt at preventing its fruition would be as futile as hoping to stop the earth from revolving around the sun."**

E. Fermi

Even when physicists are made aware that a program of fundamental research is to be undertaken, the problems have just begun. In the first place, topflight physicists are required; second-raters will not only fail to produce, but will eventually discredit and discourage the support of research by even the most far-sighted of administrators. Since the men of well-established reputation are already in secure positions, a start must be made with young men of promise. We are then faced with another question: Is there a Bardeen or Purcell in our crew of young physicists? The answer is that recognizing an outstanding physicist or a Nobel Prize winner after he has won acclaim is far easier than before. In general, the only people who knew that Bardeen and Purcell were capable physicists prior to their major accomplishments were the community of physicists in this country and abroad. Ultimately, the decisions on performance must be made in terms of someone's judgment, and it must be the judgment of responsible scientists if first-rate research is to be obtained.

"The more we know about a subject, the more intelligently we can deal with it."

J. A. Hutcheson

Now, suppose we have good physicists. To establish a tradition, we must keep them; we must build an environment in which physicists can perform happily and effectively, in which they are free to study, think, and work along lines that they determine for themselves. We must have an administration that understands and is sympathetic to the problems of the physicist and of fundamental research. These problems are quite unique, and industry has had far less overall experience here than in other areas of technical endeavor.

The environment required depends to a great extent on some of the idiosyncrasies and characteristics of physicists as a group. Among the attributes that contribute greatly to the success of a physicist are his undivided interest in his field of research and loyalty to his professional standards. A physicist does not work according to a time clock. If he is worth having at all, he will devote his energies almost completely to his professional activities. The hours he spends in the laboratory may be a fraction (and perhaps the least fruitful) of the time he spends in physics. In pursuit of his scientific interests, he sets for himself standards of perfection and goals for achievement that are usually far above those that could be demanded by a company.

By the very nature of his work, the physicist is not a conformist; success in his profession comes as the result of the most critical evaluation of experimental or theoretical statements, as the result of a creative imagination, and as the result of reconsidering and often rejecting traditional scientific points of view. Naturally, some of these traits may carry over into his other activities. If, on occasion, we should find an outstanding physicist wandering about in unorthodox attire, ignoring certain social amenities, or presenting the staff with some unique administrative problems, we should not be surprised or too concerned.

The basic elements of a fundamental research environment can be categorized as follows: (1) physical plant and facilities; (2) academic atmosphere, an educational program, and opportunities for professional growth; and (3) intellectual freedom, including a broadminded administrative approach to

*(From an address on "Atomic Energy for Power" delivered at the George Westinghouse Centennial Forum, Pittsburgh, Pennsylvania, 1946.)

the choice of problems, the evaluation of results, and the recognition of achievement.

The first of the above requirements is the easiest to visualize and, in a sense, to provide. Industrial laboratories are noted for their recognition of these needs, not only in the form of laboratories and equipment, but also in the form of capable laboratory assistants and other technical personnel.

An educational program and other opportunities for professional growth are essential to an environment for pure research. A physicist, in particular a new Ph.D., requires a continuing education in the ever-widening areas of physics. Furthermore, he must be able to discuss his problems freely and critically with a sizable number of competent physicists of varying backgrounds and points of view. Finally, he must have direct association with the outside scientific world through seminars, classes, and technical conferences.

The third category of requirements is the most difficult to visualize, but perhaps the most important. A fundamental research program must be carried out in an environment in which a physicist can use his own judgment and intuition to select within very broad limits both his problems and his methods of approach. This freedom provides the basis for more imaginative and significant results and, in addition, contributes greatly to the enthusiasm and morale of the scientist.

From the above considerations, it follows that the research physicist must be free from the pressures for solving immediate manufacturing problems. Tempting a bright young man to transfer from research to development may be trading the possibility of a revolutionary change in the industry for an immediate engineering gain of considerably less value. However, the removal of obvious pressures for tangible results is not by itself sufficient. There are many ways of recognizing immediate contributions to industry, such as rewards based on the monetary evaluation of such contributions and promotions to administrative positions. And while he is capable of viewing the universe and nature in the most abstract fashion, a physicist is only human and is subject to the human temptations of glamour and to the desire for feeling directly appreciated by and useful to his organization. Hence, there must be substituted equally appropriate means for recognizing true accomplishment in fundamental research. The man whose aptitudes or inclinations lie elsewhere should not be prevented from transferring from pure to applied research, and in fact this constitutes one of the reasons for having the former program. Nevertheless, for the physicist whose talents and value lie uniquely in the field of fundamental research, both the pressure and the temptation to indulge in application activities must be removed.

The preceding description of a proper environment for scientific research, although somewhat abstract and theoretical, is intended to disclose a working philosophy that has gone into the actual process of providing a research environment at Westinghouse. A typical example of a newly arrived young physicist, his reaction to such an environment, and assignment to a research problem may best illustrate the situation. The young man had shown considerable promise and ability in his employment interview, which resembled in many respects a university oral examination for the Ph.D. degree. At that time, he was informed that we wished to extend our fundamental research in any of three general fields, atomic physics, physical electronics, or solid-state physics. It is easy to recognize that advances in any of these general fields could be expected to have benefits to the electrical industry. The man in question chose to investigate the field of physical electronics. He was encouraged to spend his first months studying and reviewing the field, to locate the frontiers of knowledge, and to seek an interesting and significant problem. In his search, he found the educational program of the Physics Department of value. This includes weekly classes in Atomic Physics and in Solid-State Physics, colloquia on current laboratory activities, and seminars reviewing important papers in the general field of physics. After sufficient preparation, he presented a series of nine weekly seminars to the staff of the department, submitting for critical analysis and broad discussion a number of interesting problems. Largely as a result of this interaction, in particular with some of the theoretical physicists, a number of new ideas of unusual interest were crystallized. In this actual case, a new approach to an important problem in the field resulted and may soon be published. In any event, this particular young physicist had arrived at a position where he could make an intelligent choice of his future activities and was guaranteed the enthusiastic backing of his laboratory.

The Changing Role of Fundamental Research

Twenty-five years ago, the establishment of separate industrial laboratories for applying science to engineering problems was still viewed in some quarters as a revolutionary step and an unnecessary expenditure. Today, the incorporation of such activities into beautiful new laboratories under experienced and sympathetic administrators is considered an indispensable adjunct of every great industrial corporation. For some years, we have been in a transition period during which there has evolved among far-sighted executives a recognition of the importance of fundamental research. This importance is increasing rapidly, as industry demonstrates its ever-growing ability to transform basic knowledge into commercial products. Therefore, it is not unreasonable to expect that during the next 25 years fundamental research will have been generally accorded its position beside applied research as an indispensable activity in large industrial concerns. Fundamental research has benefits of an immediate nature, which justify it on the basis of immediate returns; in addition, it offers the prospect of far-reaching developments.

Engineering Briefs

THE alphabet gives the lowly insect a lot of trouble. First it was DDT—now GIXU. The latter is a new grain inspection x-ray unit designed to detect the presence of destructive wheat weevils in grain. It provides a quick method of insuring that wheat meets Food and Drug Administration infestation standards. About a handful of wheat—a carload is judged on the insect content of 100 grams—is placed in a tray film holder and radiographed. The presence of either egg or adult weevil can then be detected on the negative. With this new x-ray machine a complete infestation test can be done in about 15 minutes.

DIRECT-CURRENT locomotives fed from an a-c trolley became a practical possibility three years ago with the advent of an ignitron-rectifier multiple-unit railway car. This car was tested for three months and then placed in revenue service (October, 1949). Two ignitron-rectifier freight locomotives also have seen extensive service. Now the ignitron principle returns to its first application, multiple-unit cars; 100 new commuter cars for the New York, New Haven, and Hartford Railroad will be so powered. Each car will have four 100-hp d-c motors, a 380-kva transformer, four ignitron tubes, and necessary control apparatus.

Factors Affecting Selection of *Power-Line Carrier*

R. C. CHEEK, *Assistant Manager, Application Engineering, Electronics Division, Westinghouse Electric Corporation, Baltimore, Maryland*

The man who plans the power-line carrier for a given power system is, of necessity, an inquisitive person. To provide a system that will do the intended job and cost no more than necessary, he needs a whale of a lot of information—usually more than is available to him. The need for some of it is not apparent, but extra effort in planning pays off handsomely in carrier performance.

IF POWER-LINE carrier equipment is to perform properly its essential role in the operation of a power system, its initial planning must include many factors whose importance is not obvious. Carrier provides channels for such vital functions as protective relaying, voice communication, telemetering, supervisory control, and load-frequency control, and some applications are now being made for teletype and teleprinter operation. Each of these services has certain channel requirements peculiar to it alone, and frequently combinations of two or more such functions are required on a single carrier channel. No two power systems are alike. The conditions under which carrier equipment must work for a given function on one system may differ radically from those under which it must work on another. Furthermore, the system characteristics that are most important in applying equipment for one function may be less important for another.

Because the functions that can be served by carrier differ so widely, modern carrier equipment is designed on a "building-block" basis, so that units can be selected and assembled in the proper combination to meet the requirements of a given application. Many standard combinations are available, and it is to the advantage of both the user and the manufacturer of carrier equipment to apply these wherever possible. However, the proper choice of equipment can be made only after careful analysis of many factors relative to the functional requirements and the transmission-system characteristics. Most manufacturers of carrier equipment analyze each application and make definite equipment recommendations, but to make this possible certain information must be supplied by the prospective user. This article discusses the factors that affect the choice of carrier equipment for a given application and shows why each must be considered. Whether an application is made by the user or is based upon an equipment manufacturer's recommendations, substantial risk of

CHECK LIST

- Path for carrier
- Adjoining circuits
- Voltage, length, and construction (all circuits)
- Length of parallel runs
- Existing and future carrier equipment
- Length of coaxial cable runs
- Location of power equipment in circuits
- Points to be by-passed
- Altitudes over 3300 feet
- Maximum load currents each circuit
- Maximum 3-phase short-circuit current (each bus)
- Carrier-frequency noise levels
- Attenuation of lines
- Type of coupling
- Distance between by-pass couplers
- Power sources at terminals
- Indoor or outdoor location of terminals
- Ambient temperature at terminals
- Cabinet height (72 or 90 inches)
- Operating frequency

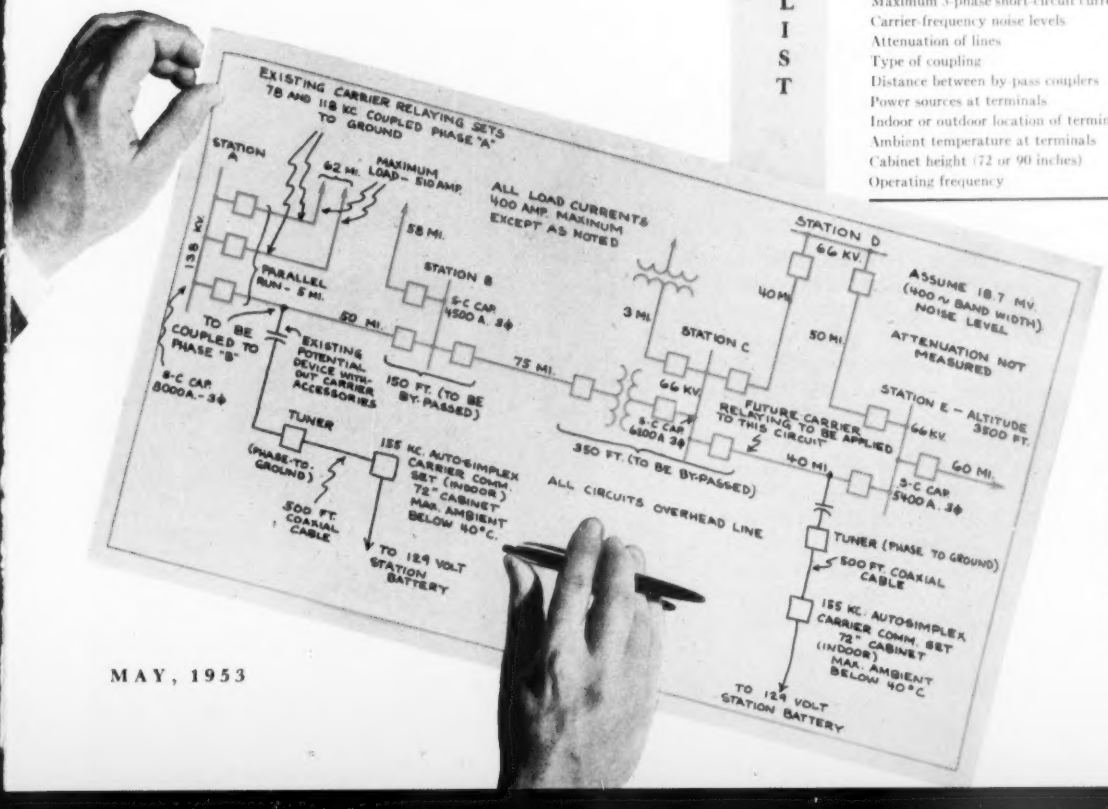

EXISTING CARRIER RELAYING SETS 78 AND 118 KC. COUPLED PHASE "A" TO GROUND
STATION A
62 MI.
MAXIMUM LOAD - 510 AMP.
ALL LOAD CURRENTS 400 AMP. MAXIMUM EXCEPT AS NOTED
138 KV
58 MI.
STATION B
PARALLEL RUN - 5 MI.
TO BE COUPLED TO PHASE "B"
8-C CAP. 8000 A. - 3¢
EXISTING POTENTIAL DEVICE WITHOUT CARRIER ACCESSORIES
TUNER
(PHASE-TO-GROUND)
500 FT. COAXIAL CABLE
155 KC. AUTO-SIMPLEX CARRIER COMM. SET (INDOOR) 72" CABINET MAX. AMBIENT BELOW 40°C.
TO 129 VOLT STATION BATTERY
20 MI.
75 MI.
150 FT. (TO BE BY-PASSED)
4-C CAP. 4500 A. 3¢
3 MI.
STATION C
66 KV.
40 MI.
50 MI.
STATION D
66 KV.
ASSUME 18.7 MV. (400 ~ BAND WIDTH) NOISE LEVEL
ATTENUATION NOT MEASURED
FUTURE CARRIER RELAYING TO BE APPLIED TO THIS CIRCUIT
5-C CAP. 6000 A. 3¢
350 FT. (TO BE BY-PASSED)
ALL CIRCUITS OVERHEAD LINE
STATION E — ALTITUDE 3500 FT.
66 KV.
60 MI.
5-C CAP. 5400 A. 3¢
TUNER (PHASE TO GROUND)
500 FT. COAXIAL CABLE
155 KC. AUTO-SIMPLEX CARRIER COMM. SET 72" CABINET (INDOOR) MAX. AMBIENT BELOW 40°C.
TO 129 VOLT STATION BATTERY

Fig. 1—The potential user of carrier equipment should supply the manufacturer with complete system information. The check list outlines the factors important in selecting the carrier assembly.

Fig. 2

Two coupling capacitors and a line tuner are suitable for short by-passes less than 100 feet.

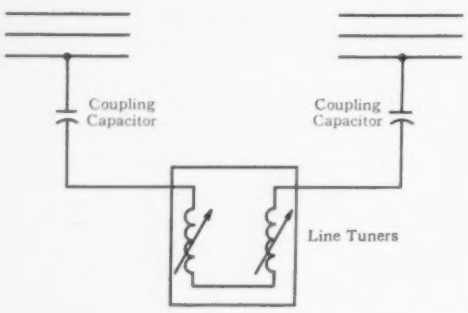
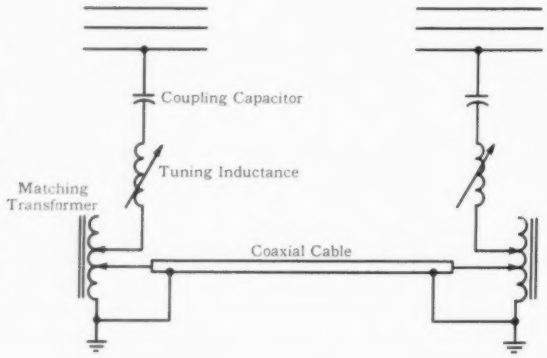


Fig. 3

The conventional long by-pass is suitable for distances up to several thousand feet, depending upon the losses in the coaxial cable at the carrier frequency that is to be used.



unsatisfactory operation is involved unless consideration is given to each factor discussed.

Type of Service Required

The most important fundamental variations among the different types of carrier assemblies are determined by the services or the functions to be performed. Most carrier channels are intended for one or more of the following functions: (a) voice communication with telephone extensions, (b) teletype or teleprinter communication, (c) supervisory control, (d) protective relaying, (e) telemetering, (f) load-frequency control, and (g) "emergency" communication (four-wire extensions) with (c) or (d).

The functional objectives of a proposed power-line carrier channel are, of course, determined by the user. Also, before proceeding with selection of the carrier equipment, he must establish many details of the end or terminating equipment for which the carrier equipment simply provides channels for information. This is necessary because such end equipments as relays, supervisory control, telemetering instruments, and the desired class of voice communication, have major effects on the type of carrier finally assembled. Discussions of the factors affecting the choice of end equipment for relaying, supervisory control, telemetering, and similar functions are readily available (see references 1, 2, 3, and 4). The various modes of operation of carrier voice-communication equipment and their relative advantages and disadvantages have been discussed previously in this publication.[5]

Power-Transmission System

Regardless of the job to be done by the carrier channel, the most important single item affecting the successful application of a carrier assembly is the power-transmission system over which it is intended to work. Unless a system's noise, attenuation, and other characteristics are given due consideration, the most advanced carrier equipment may not provide consistently satisfactory operation. Many characteristics of a power system that have little or no effect upon 60-cycle operation exert a relatively tremendous effect upon transmission at carrier frequencies. For example, where a line is tapped to supply a small load, the length of the connection between the transformer and the line can vitally affect transmission of carrier energy beyond the tap point. This section, if more than a few hundred feet, may exhibit odd quarter-wave resonance at the carrier frequency, and thereby present practically a short circuit upon the carrier channel.

The first essential to a study of the overall transmission system is a single-line diagram of the portion involved. This diagram must show not only the intended path for the carrier but also all other circuits adjoining the designed carrier circuit at all terminals and along the intended path. Voltages and lengths of all such circuits should be noted, as well as the general type of construction (overhead line or cable). This information is needed because the voltage class of an overhead line bears on its attenuation. The attenuation of a power cable at carrier frequencies is generally very high, and although a cable section may not be part of the carrier path, it presents a low impedance at carrier frequency across that path and suitable traps must be provided.

The diagram should also show which lines run physically parallel to each other with a separation of less than 1000 feet.

Typical carrier mounting methods are shown at this installation in the Charleroi substation yard of the West Penn Power Company.

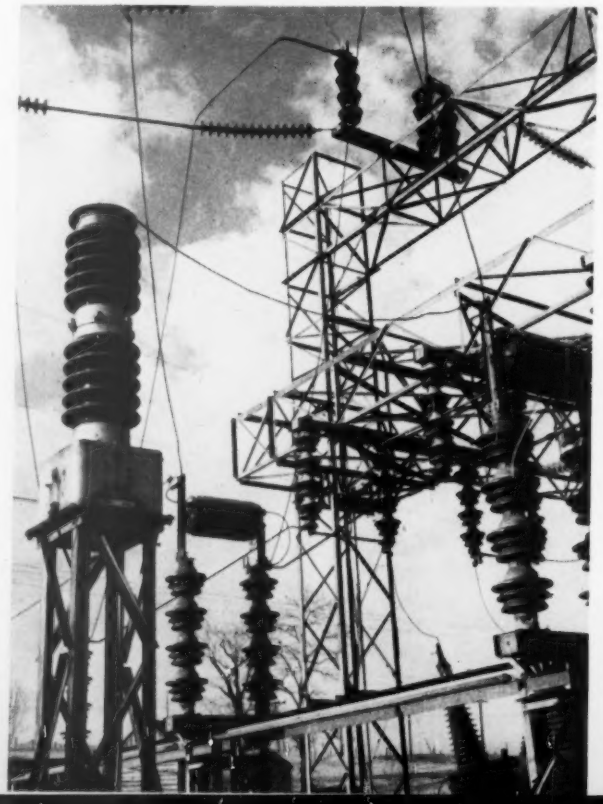
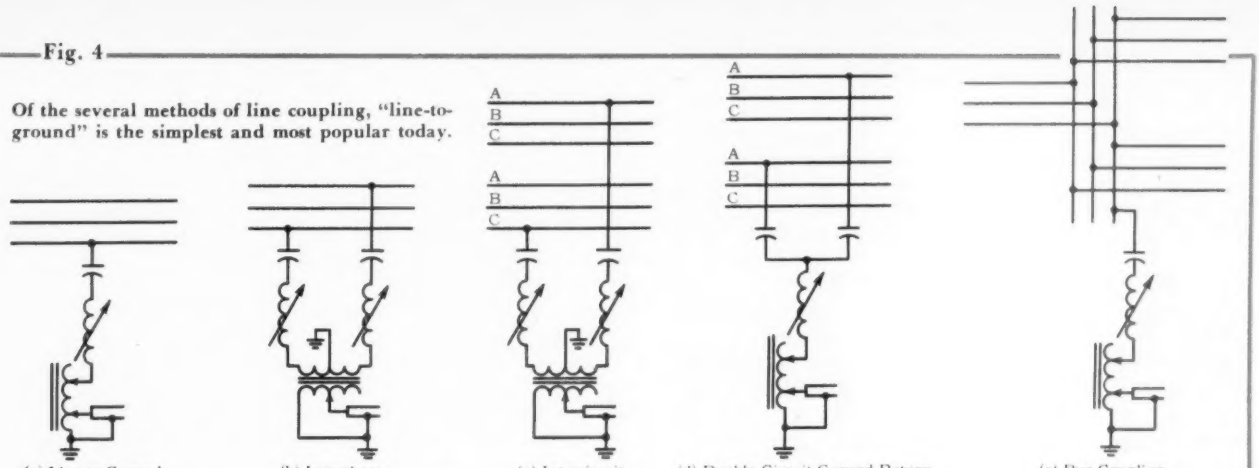


Fig. 4

Of the several methods of line coupling, "line-to-ground" is the simplest and most popular today.



(a) Line to Ground (b) Interphase (c) Intercircuit (d) Double-Circuit Ground-Return (e) Bus Coupling

The length of the parallel run should be indicated. This information is necessary because some capacitive coupling between parallel lines is unavoidable, and the probable interference between parallel carrier channels of nearby frequencies must be estimated.

The location of all existing and probable future carrier equipment, both along the intended path and on nearby circuits, is required. Their frequencies and functions should be shown. The data should include existing coupling capacitors, line traps, and line tuners, with an indication of the phases to which they are connected and the operating frequencies of the associated equipment. This information is helpful when estimating the probability of interference between the new channel and the existing channels, and it also may disclose how additional use can be made of existing coupling or trapping equipment in the application of the new channel, with resulting economies. The diagram should show whether existing coupling capacitors or capacitor potential devices are already equipped with carrier coupling accessories, or whether these need to be added. The length of coaxial cable required between line tuners and the carrier sets should be indicated.

Also essential to the carrier-application engineer is knowledge of the location of all circuit breakers, disconnecting switches, reactors, capacitor banks, regulating transformers, and other such power equipment. It must be decided whether each circuit breaker or disconnecting switch along the intended path is to be by-passed so that operation of the carrier channel is maintained when each is opened. The diagram should be marked to show in each case whether by-pass equipment is to be installed, and the line voltage at that point. It may be desirable to by-pass a switch or breaker for certain functions but not for others, and the diagram should show this information accordingly. The altitude of any such points over 3300 feet must be known so that coupling capacitors of increased voltage rating (i.e., increased creepage length) can be provided at these locations.

The maximum load current in all circuits in the intended carrier path, as well as in all circuits connected to it, and the short-circuit capability should be shown, to permit selection of the proper rating for carrier line traps where they must be used. At present, line traps are made in standard continuous current ratings of 400 and 800 amperes, and it is sufficient to indicate for each circuit which rating will be adequate. Line traps of 1200-ampere rating are made in standard and heavy-duty sizes, depending on required short-circuit capacity.

All transmission-system factors discussed up to this point can be defined by relatively simple and readily available information. However, one of the most important to carrier operation is the inherent noise level at carrier frequencies that exists at proposed carrier receiving locations. This information is almost never readily available, but is extremely important. For each of the many carrier functions and types of equipment, there is a certain minimum signal-to-noise ratio below which satisfactory operation cannot be obtained. The studies and measurements made of carrier-frequency noise on power lines [6,7] have determined only the order of magnitude of carrier-frequency noise generally encountered. They have demonstrated clearly that such noise is not defined by line-voltage class, type of line construction, or any other specific physical factors. The noise level on one system may not only differ greatly from that on another but also may vary radically with weather conditions, time of day, the season, and other factors.

The only method by which noise voltage at proposed receiving locations can be determined positively is by direct measurement of the noise at each location. The measurement should be made over a sufficient period of time to include a variety of weather conditions and system switching arrangements. A discussion of the various types of noise, and of the equipment and the techniques recommended for making noise measurements is a subject in itself.

In the absence of actual measurements of noise voltages, the engineer planning the application must make some assumption as to the probable maximum noise level. On the great majority of power systems a noise voltage of 18.7 millivolts (quasi-peak noise)[3] over 400-cycle bandwidth is not exceeded more than about 10 percent of the time. This value has often been successfully assumed. However, the potential user of carrier equipment must recognize that applications made on the basis of any assumption concerning noise levels involves some degree of risk. Since little can be done to reduce an existing noise level on a system, the only practical ways to remedy misoperation due to a poor signal-to-noise ratio are to increase the signal strength at a receiving location by application of additional line traps to the system, by the use of carrier repeaters, or by changing the carrier equipment to a type that is more immune to noise. Thus, applications made in the absence of actual measurement may in a few cases require subsequent additional investment.

Similar comments apply to estimates of the attenuation of

the intended carrier path. However, considerably more is known about the effect of line construction, size of conductors, sleet, and other factors on the attenuation of typical lines,[3] so that estimates of this factor are more reliable than those of noise. However, again, the only certain method of determining attenuation is an actual measurement. Application risks can be minimized by making such measurement[8] in advance of actual installation of the equipment.

Coupling and By-passing Arrangements

A variety of coupling arrangements have been used to transfer carrier energy between carrier assemblies and the associated power lines. In the past, phase-to-phase coupling was thought to be considerably superior to phase-to-ground coupling in terms of attenuation and noise level. However, modern theories of phase-to-ground transmission indicate that the actual return path for the carrier current with phase-to-ground coupling is not the ground itself so much as the ground wire, if one is present, and the opposite two phases of the line. As a result, phase-to-ground coupling is now generally considered to be nearly as efficient as phase-to-phase coupling. Most recent carrier installations have successfully employed this method of coupling. A major advantage is a saving in equipment because only one coupling capacitor instead of two is required at each coupling location.

Several special methods of coupling have been used in attempts to provide increased immunity of the carrier channel to switching and line-fault conditions. In intercircuit coupling, for example, the carrier energy is coupled to one phase of one circuit of a double-circuit line and to another phase of the other. With this type of coupling one circuit can be taken out of service and grounded at any point without interrupting the continuity on the other.

Other special types of coupling circuits require double-circuit lines between carrier terminals.[3] If it is desired to use one of these special arrangements the theoretical advantages should be weighed against the economics of the situation. They generally require a larger investment in tuners and coupling capacitors than the more conventional methods. If recommendations are being requested from a manufacturer, the information supplied should state whether a special preference exists for a particular type of coupling, or whether the choice of the type is to be left to the manufacturer's recommendations. In the latter case the phase-to-ground system is usually chosen because of its economy.

A factor affecting the choice of equipment for by-passing purposes is the distance between the coupling capacitors that will provide the by-pass coupling. If this is less than 50 feet, some economies can usually be effected by using a single tuning assembly located between the coupling capacitors, with insulated aerial leads to the capacitors instead of the more expensive coaxial cable with matching transformers. Depending on the frequency of the proposed channel, and the line voltages (which determine the capacitance of the coupling capacitors), a single inductance may be sufficient to tune both capacitors to resonance. Sometimes insulated aerial leads between capacitors may be considered undesirable, even though the distance is sufficiently short to permit its use. In such cases, the conventional long by-pass system, using two separate tuning assemblies with matching transformers and coaxial cable, is normally used.

Power Sources for Carrier Assemblies

Because the functions for which carrier is applied are often vital to the continuity of operation of a power system, the power sources from which carrier assemblies operate deserve careful consideration. Practically all carrier assemblies used for protective relaying, remote tripping, and supervisory control operate directly from 129- or 258-volt station batteries. However, only recently have communication and telemetering assemblies been available[9] that can operate directly from station batteries. As a result, the trend in the selection of equipment for all carrier functions is now definitely toward direct battery operation.

Direct-current operation requires consideration of several factors not normally important with a-c sources. Because a power-station battery is normally ungrounded, d-c carrier equipment must likewise be isolated from ground. The noise due to battery chargers and the operation of other power equipment is potentially detrimental to the functioning of carrier, unless it is designed with adequate filters. Station-battery ripple voltage should not exceed 0.5 percent and the ripple frequencies should be 50 cycles or above. Special filtering equipment may be necessary if these limits are not met.

Another problem often encountered with d-c power supply is voltage variation. The differences in battery voltage between charging conditions and normal usage can be detrimental to tube life unless regulators are included to maintain relatively constant tube-heater temperatures. Modern d-c carrier equipment contains heater regulators that permit battery-voltage variation between 100 and 150 volts (for nominal 129-volt station battery) without harming the tubes. A greater range of initial setting or of normal variation requires special consideration by the manufacturer. Proportional limits apply for 258-volt station batteries. In any case the nominal voltage of the available battery must be stated.

In the case of a-c powered equipment, consideration should be given to whether an emergency source (usually the station battery) is to be used as an emergency supply. If so, the battery voltage, the relative desirability of manual and automatic transfer, and the possible use of the emergency supply for equipment other than the carrier set should be considered in selection of emergency power-supply equipment.

The normal a-c supply voltage is the nominal 120 volts ±

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2—"By a Flick of the Finger (Supervisory Control)," by W. A. Derr, *Westinghouse* ENGINEER, November, 1949, pp. 162–7.

3—"Power-Line Carrier Application," by R. C. Cheek, *Electrical Transmission and Distribution Reference Book*, Chapter 12, Westinghouse Electric Corporation, East Pittsburgh, Pa., Fourth Edition, 1950.

4—"A High-Speed Telemetering System with Automatic Calibration," by W. E. Phillips, AIEE Paper 51–228, June, 1951.

5—"Power-Line Carrier Communication," by R. C. Cheek, *Westinghouse* ENGINEER, September, 1947, pp. 151–154.

6—"A Study of Carrier-Frequency Noise on Power Lines—Part I. Theoretical Considerations and Measuring Techniques," by R. C. Cheek and J. D. Moynihan, *AIEE Transactions*, Vol. 70, 1951.

7—"A Study of Carrier-Frequency Noise on Power Lines—Part II. Results of Field Measurements," by R. C. Cheek and J. D. Moynihan, *AIEE Transactions*, Vol. 70, 1951.

8—"Report on Methods of Measurement at Carrier-Current Frequencies," Power Group of the AIEE, Carrier-Current Committee, *AIEE Transactions*, Vol. 67, 1948, pp. 1429–32.

9—"A Flexible New Line of Power-Line Carrier Equipment," by F. B. Gunter, presented at AIEE Winter Meeting, New York, New York, January, 1953.

10 percent. If it differs from this an auxiliary transformer must be provided.

Location of Carrier Assemblies

In the past, carrier assemblies were commonly located outdoors in weatherproof cabinets. This is undesirable from many standpoints; for example, servicing and adjusting are inconvenient in bad weather, underground phone extensions must be provided, as well as power-supply leads. Modern practice is to locate the carrier assemblies indoors whenever space permits, using coaxial cable, either buried or in ducts, between the carrier sets and the outdoor line tuner. However, outdoor cabinets can be used if local conditions require.

Carrier equipment is usually designed for ambient temperatures ranging between −40 and −60 degrees C. However, some types of crystal-controlled equipment may not function properly in temperatures below −20 degrees C. If the temperature falls below this, it must be decided whether the carrier cabinets should be heated in some manner. Another factor deserving consideration in connection with ambient temperature is whether other carrier cabinets or other types of heat-radiating equipment will be located directly adjacent to the assembly. The rated ambient-temperature limits of carrier equipment assume no other heat-radiating sources directly adjacent to the carrier cabinet and that free space is available on all sides of the cabinet for air circulation.

A cabinet height of 72 inches has come to be nearly standard for carrier assemblies, although a few complex assemblies require a taller cabinet.

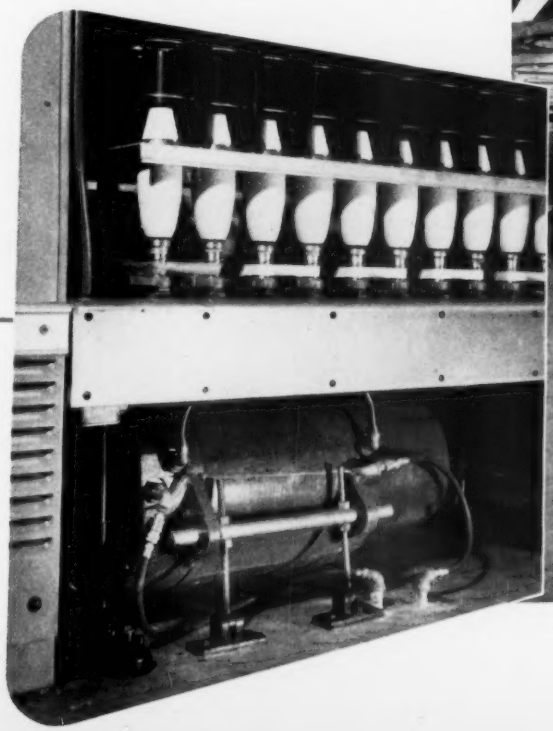
Selection of Operating Frequency

Practically all modern carrier equipment for all functions is crystal controlled. This requires selection of the operating frequency in advance of installation. Usually the prospective user knows what frequencies are available in his particular interconnected systems group for the function he intends to perform with the carrier channel. The desired frequency must be specified to the manufacturer to permit inclusion of the proper frequency-determining components in the assemblies. Modern carrier equipment is built for frequencies as low as 40 kc and as high as 200 kc.

(To be concluded in the next issue)

What's NEW

Uniform temperature throughout the length of a textile spinning frame is a highly desirable quality. A "hot spot" at any point means that the yarn from that vicinity on the frame will contain less moisture, and will therefore have different characteristics. This usually means yarn breakage. This new 20-horsepower motor is water-cooled, and thus can be mounted under the frame and have little or no effect on the temperature and humidity. The motor below is mounted under the new Saco-Lowell "Gwaltney" spinning frame. It is a totally enclosed, non-ventilated type to exclude lint. To make the motor suitable for mounting in the very confined space under the frame, it is built on a smaller than normal frame size for the rating and is built without feet. Bracket lugs are provided for mounting the motor on a pivoted arrangement under the frame. To take the heat away from the motor and maintain the desired low surface temperature, water tubes with large surface areas are installed inside both brackets near the end turns.

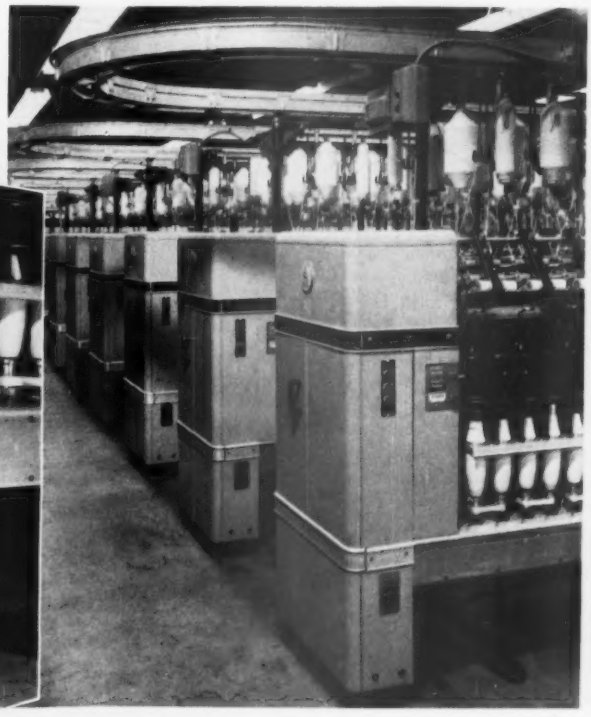


Water-Cooled Motor

Overload Indicator with a Memory

THERE HAVE long been devices of one sort or another to indicate the presence of overloads on conventional distribution transformers. But now comes one that not only calls attention to overload conditions as they occur, but remembers what has happened to the transformer it is watching over since it was last checked. It presents this history visually.

The temperature-sensing part of what is called the type PL



(performance log) indicator is a bimetallic thermostat embedded in the windings of the transformer. The visual indication is a red light and dial pointer. A relay supplies the brains, or memory. The first five overloads detected by the bimetal turn on the red light each time, and the pointer counts them up on the dial. But after the fifth time, although the pointer continues to count the overload conditions, the red light decides it's time something was done to correct such a situation, and it stays on. Readily visible from the ground, it prompts the lineman to report the condition. A reset button makes it possible to turn the light off and return the pointer to zero.

Not only can distribution people now load their conventional transformers by copper temperature, but the new overload indicator can be used as a measure of load growth, and hence as a guide as to when replacement is necessary.

Look! Bands, but no Solder!

THE METHOD of banding armatures hasn't changed much since the first d-c machine engineers 65 or 70 years ago were rudely taught the meaning of centrifugal forces. The earliest "bands" were of string but these soon changed to steel wire wrapped several times and perhaps in two layers over the coils. The two ends are brought together and hooked with sharp, hairpin loops. These loose ends are then fastened in place by soldering to the thin metal clips. In fact the whole band of wires has been generously smeared with solder.

The new way is to do it without solder. The banding is the same—up to the point of applying the clips to keep the two ends from coming loose when the machine is turning at perhaps several thousand rpm. The two ends of the band join together and lock into each other with a hairpin loop. The free ends outside of the loop are held down by banding clips. Two clips are used. One is laid in first before the banding is started. The other is applied under the last few turns but over the last turn. The two projecting ends of the clips are folded together much as the cupped fingers of two hands lock together. The joint has undergone extensive research examinations and been proved stronger than the banding wire itself.

Many things can be said in favor of eliminating solder. Solder

is a poor structural material and it does not team up well with steel wire, which has great strength, to make a desirable mechanical structure. Its melting point is low, so that during a short circuit or a prolonged overload it may soften and release the band wires. The result is a destructive failure. In all fairness to solder it must be said that there have been few such occasions out of the many thousands built in this way.

Even experts find it difficult to get uniform, consistent results with solder. Then solder, containing a high proportion of lead, is heavy. Because it is applied to the rotor surface it adds materially to the inertia force without contributing much strength. Finally, solder consists of materials growing in scarcity.

The solderless-banding technique has been applied to several hundred d-c armatures and wound-rotor armatures. Among these are the large-diameter and the high-speed machines, which offer the largest centrifugal forces. Results, to date, have been perfect on all these machines.

Body Armor for Marines

This is not mere idle target practice, but a demonstration of an armor vest now being used by the Marine Corps. The armor consists of curved (to fit the body) plates of Doron, ⅛ inch thick and 5¼ inches square. About 20 plates are sewn in each jacket in overlapping fashion. Doron is made by applying heat and pressure to layers of resin-impregnated glass cloth. When a shell fragment or small caliber bullet strikes the material the layers of cloth separate, thus providing a cushioning effect that stops the bullet. The photo below shows a mushroomed .45 caliber bullet taken from a plate.

Personality Profiles

If anyone still retains a mental picture of a research scientist as a long-haired, absent-minded, hard-to-get-along-with human after reading the article on page 103, he would do well to meet its author, *Dr. Daniel Alpert*. Such notions would be quickly dispelled.

Alpert is that relatively rare combination of physicist and administrator. He has a solid background of research in physics behind him, and has been manager of the Physics Department of the Research Laboratories since 1950.

A native of Connecticut, Alpert graduated (magna cum laude) from Trinity College in 1937. He then spent four years at Stanford University, partly under a fellowship, partly as a teaching assistant and research associate. He was awarded his Ph.D. in 1942. During this interval he was a member of the group that developed the klystron. In 1941 he joined Westinghouse as a Research Fellow, and shortly thereafter became a member of the Electronics Department.

As a research physicist in the Electronics Department, Alpert played a part in several significant developments. Perhaps outstanding among them was the TR switch for radar, which he patented in 1943. Many of his efforts since then have been aimed at fundamental research, particularly in the fields of gaseous and physical electronics.

Alpert's interests are by no means confined completely to the laboratory. He has been a member of his local school board since 1947, and its president for two years; he is an active skier and tennis player; he is a member of numerous physics associations, including the American Physical Society, and is currently chairman of this society's Division of Electron Physics.

• • •

Few jobs offer as much variety as that of *Robert M. Leedy*. As a liaison engineer, he acts as coordinator for company-wide activity in the application of aluminum. This involves disseminating information on aluminum applications to all company divisions, assisting division engineers with special application problems, and, as his title implies, acting as a liaison between company divisions with similar problems. And this is but one phase of his job; its scope ranges from plastics to isotopes.

Leedy's education for this many-faceted job was as a metallurgist. He graduated from Carnegie Institute of Technology in 1947 with a B.S. in Metallurgical Engineering, and has continued his studies there in the Graduate Night School. His first job with Westinghouse was as a metallurgical engineer in the Materials Engineering Department, where he worked on both ferrous and nonferrous applications. He joined the Liaison Engineering Department in 1950.

His present job and the jobs he held during his school days suggest that Leedy likes his work varied. During his spare time after school and summers, he managed a general store, did aerial surveying, and supervised farm programs for the government.

The coauthor of the aluminum story, *S. A. Rosecrans*, is also a metallurgist, and also a graduate of Carnegie Institute of Technology. Rosecrans was one of the first group of George Westinghouse Scholars, and at various intervals during his college training took time out to work in several Westinghouse plants. Upon graduation in 1942, he joined what was then called the Feeder Engineering Department and is now the Materials Division. His work as a metallurgist has been largely in the field of nonferrous materials, and for the past few years Rosecrans has been supervisor of the group concerned with such metals.

• • •

This is *Robert C. Cheek's* fifth article for the ENGINEER. A lot has happened to Cheek since his last article in 1947. Probably one of his proudest moments came when he was given Eta Kappa Nu's award as the "Outstanding Young Electrical Engineer for 1949." In 1951, he moved from headquarters Electric Utility Engineering to the Electronics Division in Baltimore to become assistant manager of Application Engineering, in charge of commercial electronics products. And finally, Cheek is in the process of putting the finishing touches on a new home.

The house has at least one unique feature—although no surprise to anyone who knows Cheek—a completely shielded room where he houses his amateur radio station, W3LOE. No interference will ever come from this place. The room walls are lined with aluminum, the doors have aluminum-sheet interlining, metal stripping lines the door frames, and metal-framed window screens complete the total shielding. A spurious radio wave that escaped this prison would be far too weak to do any damage to a neighbor's television reception.

• • •

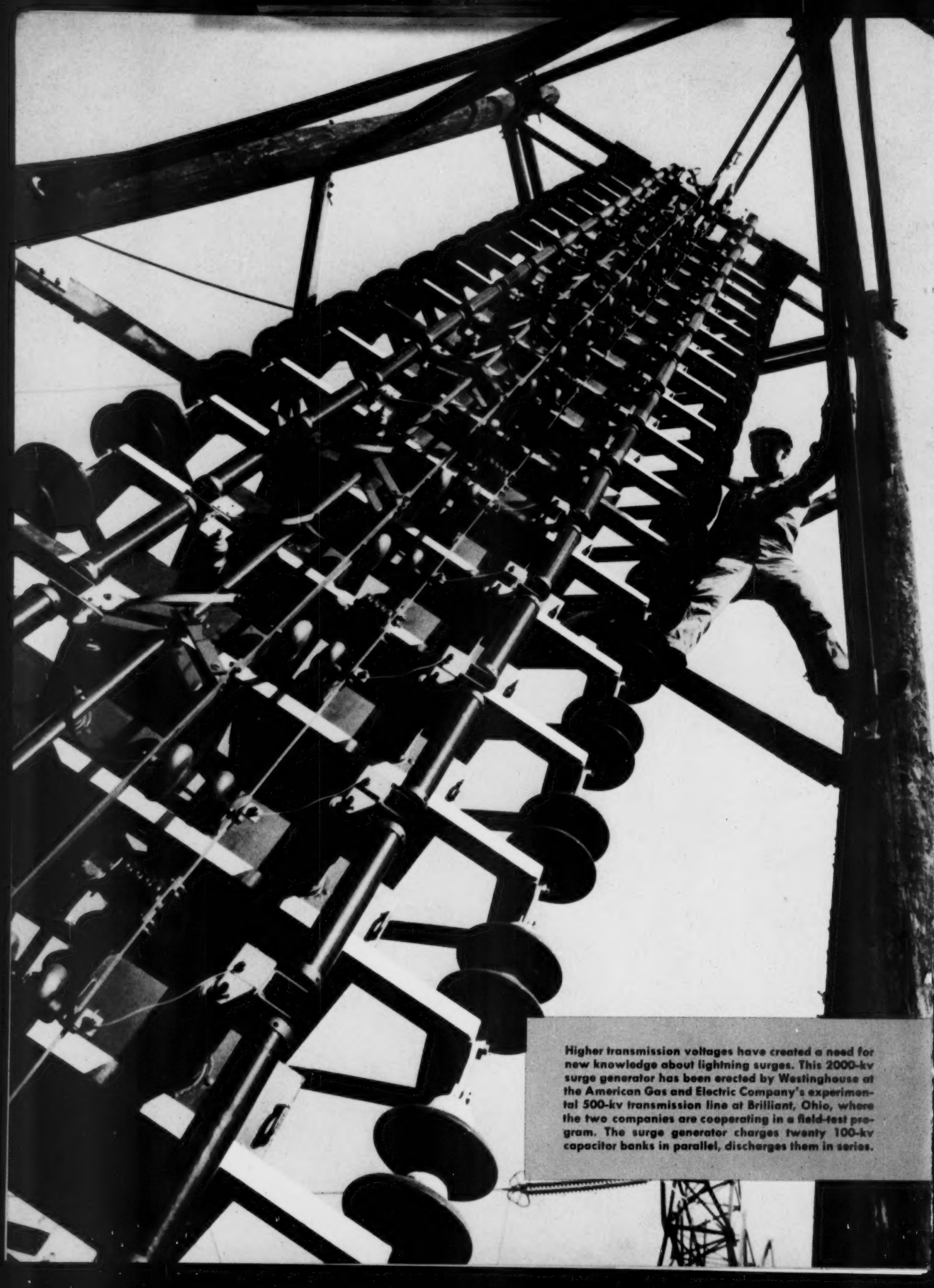
Graham L. Moses is an already familiar name to most of our readers. As manager of the section responsible for developing new generator insulations, he has written several articles in recent years covering various phases of his work.

• • •

W. E. Anderson has virtually grown up with the filament-lamp industry. When he joined the Lamp Division in 1916, carbon-filament lamps were on their way out and the tungsten version was just beginning to flex its developmental muscles. Since then he has worked on every major development project in filament lamps and consequently holds a number of patents.

Anderson spent his early years in Connecticut; he was raised in Stamford and educated in New Haven at Yale, from which he graduated in 1913 with a Ph.B. in Electrical Engineering.

For almost as long as Anderson has been associated with lamp design, *George R. Moritz* has been connected with the chemistry and metallurgy of materials used in those lamps. Moritz joined the Chemistry and Metallurgy Department of the old Westinghouse Lamp Company in 1926, shortly after graduating from Lehigh University as a metallurgical engineer. He has, he says, been enjoying himself ever since. He loves a tough development problem, especially if it deals with tungsten, and has worked on dozens of just that kind. He has also worked on such diversified projects as metallography of nickel and molybdenum wires, studies on numerous fluorescent powders, and various particle studies using an electron microscope. He is, incidentally, a charter member of the Electron Society of America.



Higher transmission voltages have created a need for new knowledge about lightning surges. This 2000-kv surge generator has been erected by Westinghouse at the American Gas and Electric Company's experimental 500-kv transmission line at Brilliant, Ohio, where the two companies are cooperating in a field-test program. The surge generator charges twenty 100-kv capacitor banks in parallel, discharges them in series.